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THE SURFICIAL GEOLOGY OF THE FOREMOST-CYPRESS HILLS AREA, ALBERTA, CANADA

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

OF DOCTOR OF PHILOSOPHY

DEPARTMENT OF GEOLOGY

by

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EDMONTON, ALBERTA

SEPTEMBER, 1964

UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled, "The Surficial Geology of the Foremost-Cypress Hills Area, Alberta, Canada", submitted by John Arthur Westgate, in partial fulfilment of the requirements for the degree of Doctor of Philosophy.

ABSTRACT

The Foremost-Cypress Hills area is divided into six physiographic units: Cypress Hills Plateau, upland areas, till plain, lacustrine plains, river channels, and canyons. The South Saskatchewan River drains the northern part of the area, and the Milk River drains the southern part. A small internal drainage basin is centred on Lake Pakowki.

Glaciation only slightly modified the preglacial physiography of the upland areas but considerably altered that of the lower tracts. The preglacial valleys in places contain more than 250 feet of glacial drift. The Ancestral Oldman River and the Ancestral Milk River drained the map-area in preglacial times; both occupied broad, open valleys and flowed to the northeast.

End moraine, including washboard moraine, is the most widespread glacial land form. Others present include ground moraine, hummocky disintegration moraine, linear disintegration ridges, drumlins and drumlinoid ridges, kames, eskers, and flutings. Proglacial land forms present in the area include outwash aprons, a loess plain, glacial lake basins, meltwater channels, and spillways.

The colour, texture, pebble composition, heavy minerals, and carbonate content of the several till sheets in the map-area were studied. The texture of the tills is largely controlled by the underlying bedrock, and the younger tills contain less carbonate pebbles than the older. The carbonate content of the till matrix, and the heavy minerals must presently be regarded of little value as parameters in differentiating the till sheets.

The maximum altitude reached by the Laurentian glaciers in the map-area was 4500 feet. At this time the ice was 2300 feet thick at Medicine Hat, about 1500 feet thick at Foremost and Manyberries and about 1000 feet thick at Aden. In the western part of the area the glaciers moved southward, but farther east they were forced to flow southeastwards along the stretch of low land between the Cypress

Hills and the Sweet Grass Hills, which both stood as nunataks at the time of the most extensive glaciation.

The Pleistocene deposits are divided into the following stratigraphic units, in order of decreasing age: Saskatchewan gravels and sands; sediment deposited in proglacial lakes that formed along preglacial valleys as a result of damming downstream by ice; pre-Wild Horse drift, including the Cypress Hills loess; Wild Horse drift; Pakowki drift and Manyberries volcanic ash; Etzikom drift and Oldman drift. The drift sheets are morphostratigraphic units; all were deposited at the time of a significant glacial advance. A radiocarbon date of $29,200 \pm \begin{matrix} 8100 \\ 4000 \end{matrix}$ years B.P. (GX-0102) on the upper part of the preglacial Saskatchewan gravels and sands, the lack of severely weathered horizons in the drift, and the fresh-looking morainal topography suggest that all these drift sheets are of Wisconsin age.

ACKNOWLEDGEMENTS

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Mr. L. Lindoe, director of research, Medicine Hat Brick and Tile, provided data on the structure and stratigraphy of the Cypress Hills district, the Pleistocene deposits of the Medicine Hat area, and loaned the writer several fossils which he had collected from the local Pleistocene deposits.

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The invertebrate fossils listed in Chapter V were identified by Dr. R. Green, Research Council of Alberta, and the vertebrate fossils listed in Appendix C were identified by Dr. L.S. Russell, Royal Ontario Museum. Thanks are extended to Mrs. L. Laidlaw, Convenor of the Museum Committee of Medicine Hat, for the loan of a tooth of Mammuthus primigenius.

The map of the topography of the bedrock surface was compiled from data supplied by Texaco Exploration Company, British American Oil Company, Pan American Oil Company, Hudson Bay Oil and Gas, Royalite Oil Company, Alberta Oil and Gas Conservation Board, and Renbar Drilling, Ltd., Medicine Hat. Drs. J. Campbell and W. Geiger, Research Council of Alberta, also provided useful information.

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Maps 2 to 7 and the legends to the other maps were drafted by Mr. J. Groot and Mr. F. Copeland respectively, both of the Research Council of Alberta. The remaining maps and all the figures were drawn by the writer and reproduced using the facilities of the Research Council of Alberta. Mr. F. Dimitrov, Department of Geology, University of Alberta, photographically reduced the figures and printed one copy of each; he also made some of the plates. Dr. H. Baadsgaard set up the equipment for the determination of the carbonate content of the tills. The typing was done by Mrs. D. Haugan and Mrs. S. Binda.

Discussions on topics related to the writer's field of research were held with staff members of the Department of Geology and Research Council of Alberta as well as with fellow graduate students. It is difficult to define in specific terms the contribution of such talks, but many ideas now incorporated in this manuscript germinated in the spoken word.

Finally, the writer would like to acknowledge the help and cooperation given by his wife

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CHAPTER I - INTRODUCTION

Location

The Foremost-Cypress Hills area is situated in the southeastern corner of the province of Alberta. It covers approximately 6,200 square miles and is bounded by 49th and 50° North Latitude and 110° and 112° West Longitude (Figure 1). The province of Saskatchewan lies immediately to the east, the United States of America to the south.

Objectives of Present Study

This study was undertaken to determine the distribution, thickness, composition and origin of the Pleistocene deposits of the Foremost-Cypress Hills area; to provide maps that will aid future development of economic resources, especially ground water and constructional materials; and, to establish the Pleistocene stratigraphical succession. Basically, the report attempts to unravel the sequence of geological events that took place in the map-area during the Pleistocene Epoch.

Method of Study

Firstly, aerial photographs (scale approximately one and a half inches to one mile) were examined with the aid of a stereoscope to classify the landforms and to deduce the lithological composition of the surficial deposits. The boundaries were then plotted on planimetric sheets to a scale of one inch to one mile.

This interpretation was then checked in the field and boundaries altered where necessary. Deposits were examined along road cuts, river valleys, and frequently by shallow digging. Sections were recorded and samples collected for

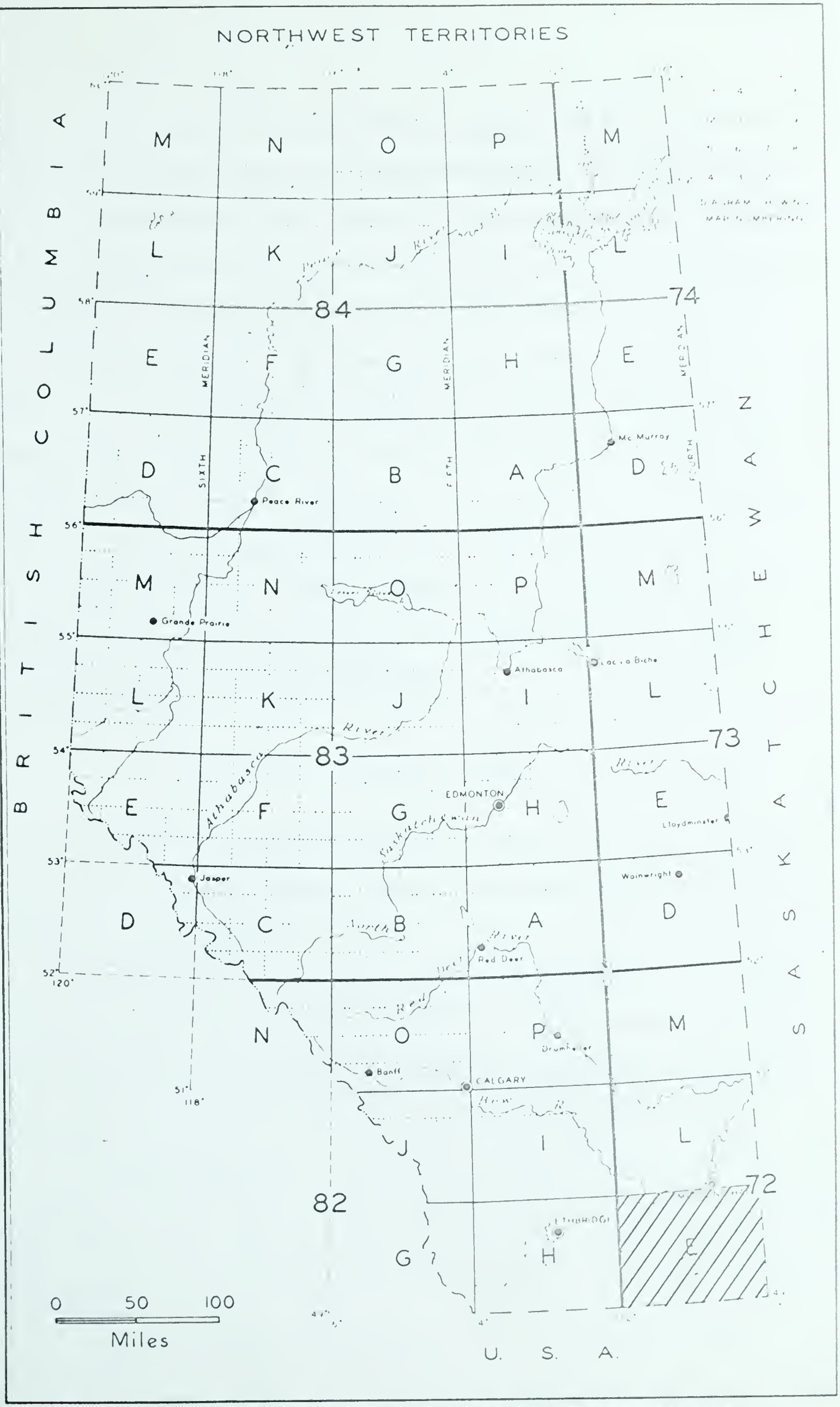


Figure 1. Location of the Foremost-Cypress Hills area, Alberta

analysis in the laboratory. The eastern half of the map-area was systematically covered: north-south traverses were one mile apart, east-west traverses two miles apart. The western half was mapped to a scale of one inch to four miles with traverses spaced four miles apart. Here, each land form unit is much more extensive and maintains its essential characteristics over long distances.

After the fieldwork, which extended over the seasons 1961 to 1963 inclusive, the aerial photographs were studied again and the final boundaries plotted. The surficial geology of the eastern half of the map-area is shown on six separate planimetric sheets to a scale of one inch to one mile. The surficial geology of the whole area is presented on a map to a scale of one inch to four miles.

Seismic shot hole data and logs of water wells provided valuable subsurface information that was used, in conjunction with field observations, to compile the maps on drift thickness and bedrock topography.

Maps and Air Photograph Coverage

Planimetric sheets numbered 72E 1-16, to a scale of 1:63,360, have been compiled by the Photographic Survey Corporation Limited from air photographs taken in 1951 to a scale of 1:40,000.

The only topographic map of the area is the Foremost Sheet - 72E National Topographic System. It has a scale of 1:250,000 and a contour interval of 100 feet. This map was produced and printed by the Surveys and Mapping Branch, Department of Mines and Technical Surveys, 1958, from air photographs taken in 1950.

The bedrock geology of the area was mapped by Russell (1940) and his work was published by the Geological Survey of Canada. There are two maps; the Foremost Sheet (map 566A) and the Dunmore Sheet (map 567A). Both have a scale of one inch to four miles.

A soils map of the Medicine Hat area was prepared by Wyatt and Newton (1926). It has a scale of one inch to three miles. Later, Wyatt, et al. (1941) compiled a map of the soils of the Milk River area. These two maps provide complete coverage of the soils of the map-area.

Vertical air photographs, with a scale of approximately one and a half inches to one mile, cover the whole area.

System of Land Survey - Site Reference Method

The eastern boundary of the map-area is the 110° Longitude. In the land survey system of western Canada, this is the Fourth Principal Meridian. All locations mentioned in this report are west of this meridian. The area has been surveyed into townships, ranges and sections, and Figure 2 is a diagram of a township showing how the sections are numbered and subdivided into legal subdivisions.

Previous Work

Prior to the present study, no detailed survey of the Pleistocene deposits of the Foremost-Cypress Hills area had been carried out. In the course of mapping the bedrock geology, however, geologists had established the general physiographical evolution of the area, outlined some of the prominent morainal tracts and glacial lake basins, and described surficial deposits exposed along the major river valleys.

The first geologist to visit the area was Sir James Hector (Hector, 1861), the physician and geologist on the Palliser Expedition of 1857-1860. He noticed the veneer of glacial drift present throughout the Western Prairies, and, like most of his contemporaries, believed it to have formed by the melting of debris-clogged icebergs in a glacial sea. Hector visited the Cypress ("Cypres") Hills and commented on its capping of "shingle" to which he assigned a Tertiary age.

Figure 2. Diagram of a township showing the numbering of sections and the subdivision of a section into 16 legal subdivisions

Dawson (1875) provided the first geological description of the area, for Hector's work dealt mainly with what is now central Alberta. Later, Dawson revisited southern Alberta for the Geological Survey of Canada, and produced the classic "Report on the Region in the Vicinity of the Bow and Belly Rivers" (Dawson, 1885). In this he ably describes the physiography, the extent to which glaciation modified the preglacial condition of the country, variation in drift thickness, stratigraphy of the "superficial" deposits, and the maximum elevation and provenance of glacial erratics. Although, for the most part, concerned with features in southwestern Alberta, his comments are very pertinent to the present map-area. Like Hector, Dawson believed that all glacial deposits originated in a glacial sea. He envisaged land submergence in southern Alberta of several thousand feet, subsequent incursion of a glacial sea from the northeast, and then its expulsion on emergence of the land. Holding these ideas, he found difficulty in explaining the great coulees which traverse southern Alberta, admitting that Warren Upham's theory of continental ice sheets and channel incision marginal to them was better. Nevertheless, Dawson still clung to his inundation concept.

McConnell, (1885), Dawson's former assistant, described the geology of the Cypress Hills - Wood Mountain area. He presented the first detailed description of the Cypress Hills conglomerate, noting that its constituents came from the Rocky Mountains to the west. He thought the conglomerate to be of Miocene age (then including what is now called Oligocene) on the basis of vertebrate remains found in it, and said it was deposited "in a dilation of some large river flowing eastward from the Rocky Mountains" (ibid., p. 35c).

McConnell found the maximum elevation of glacial deposits on the slopes of the Cypress Hills to be around 4400 feet and recognised rocks in the drift that had come from the northeast. In addition, he recorded the Pleistocene deposits exposed along the South Saskatchewan River and identified locations of some preglacial valleys.

His views on the genesis of glacial deposits resembled those of Dawson.

Dowling (1917) rejected the glacial sea theory. In his report "The Southern Plains of Alberta", he explains the numerous entrenched channels (Verdigris, Etzikom, Chin, etc.) as ice-marginal valleys that formed during the recession of the "Glacial ice sheet". The sequence of changes in the drainage pattern of the area is broadly outlined and later workers have concurred with Dowling in this respect.

Alden (1924) wrote an important paper entitled, "Physiographic Development of the Northern Great Plains," in which he identified Tertiary and Pleistocene erosional surfaces. The type locality for his oldest surface--the Cypress Plain--is the Cypress Hills, Alberta. This work was amplified in 1932.

Allan (1926) discussed the relation of the geology to the soils in an appendix to the report on the soils of the Medicine Hat Sheet by Wyatt and Newton. He commented on the preglacial courses of the Oldman, Bow and South Saskatchewan rivers, the origin of the surficial deposits and the glacial history. He wrote a similar report for inclusion in the bulletin on the soils of the Milk River Sheet (Wyatt, et al., 1941).

A comprehensive treatment of the physiography of the map-area is found in publications by Williams (1929) and Williams and Dyer (1930). Equivalents of Alden's erosional surfaces were recognised, glacial landforms described and post-glacial uplift postulated.

Johnston and Wickenden (1931) delineated the moraines and glacial lakes in southern Saskatchewan and southern Alberta. They believed the former became progressively younger to the northeast and their map shows these moraines to have an approximate northwest to southeast strike.

Later, Wickenden (1937) observed a moraine that extended northwest across southwestern Saskatchewan to the northern side of the Cypress Hills in Alberta, then southwest to the northern end of Pakowki Lake, then west and northwest to

Lethbridge. To him this marked the limit of a major glacial advance. (It is most likely that this moraine is the Etzikom End Moraine of the present report).

A study of the age and distribution of Albertan end moraines was undertaken by Bretz (1943). During 50 days of fieldwork he mapped all the moraines occurring in an area of about 40,000 square miles. His succession of meltwater dischargeways and associated glacial lakes in southeastern Alberta is very similar to that of Dowling (1917) and Williams (1929).

The Pleistocene deposits of southwestern Alberta have been studied by Dawson (1883, 1895a, 1895b), Horberg (1952, 1954) and Stalker (map 41-1962, 1963a, 1963b). Parizek (1961) mapped the Willow Bunch Lake area, south-central Saskatchewan. In the United States, Calhoun (1906) mapped the surficial geology of north-central Montana and Howard (1960) northeastern Montana. A map of glacial deposits east of the Rocky Mountains was published by the Geological Society of America (1959).

CHAPTER II - PHYSIOGRAPHY

General Setting

The Foremost-Cypress Hills area is an undulating to rolling plain dissected by steep-walled valleys and framed by the Cypress Hills to the east, Milk River Ridge to the west, and the foothills of the Sweet Grass Hills to the south. It forms part of the third prairie step.

Physiographic Units

The area may be conveniently divided into six physiographic units: Cypress Hills Plateau, upland areas, till plain, lacustrine plains, river channels, and canyons (Figure 3).

Cypress Hills Plateau

The dominating physical feature of the Cypress Hills is the nearly level plateau which slopes gently to the east and south (Plate 1). At its western extremity or "Head of the Mountain", the plateau reaches a maximum elevation of 4800 feet and drops to less than 4500 feet at the Alberta-Saskatchewan border, some 15 miles to the east. Its elevation and surface gradient is determined by the Cypress Hills conglomerate. To the north and west the plateau ends abruptly in steep escarpments, formed in part by ice-marginal meltwater flow; whereas, on the south, it gradually merges into the plain. The northern part of the plateau is dissected by trough-shaped valleys excavated into the Cypress Hills conglomerate. Most of these valleys were formed after the incision of the ice-marginal channels immediately to the north, when the local base level of the north-flowing streams was significantly lowered.

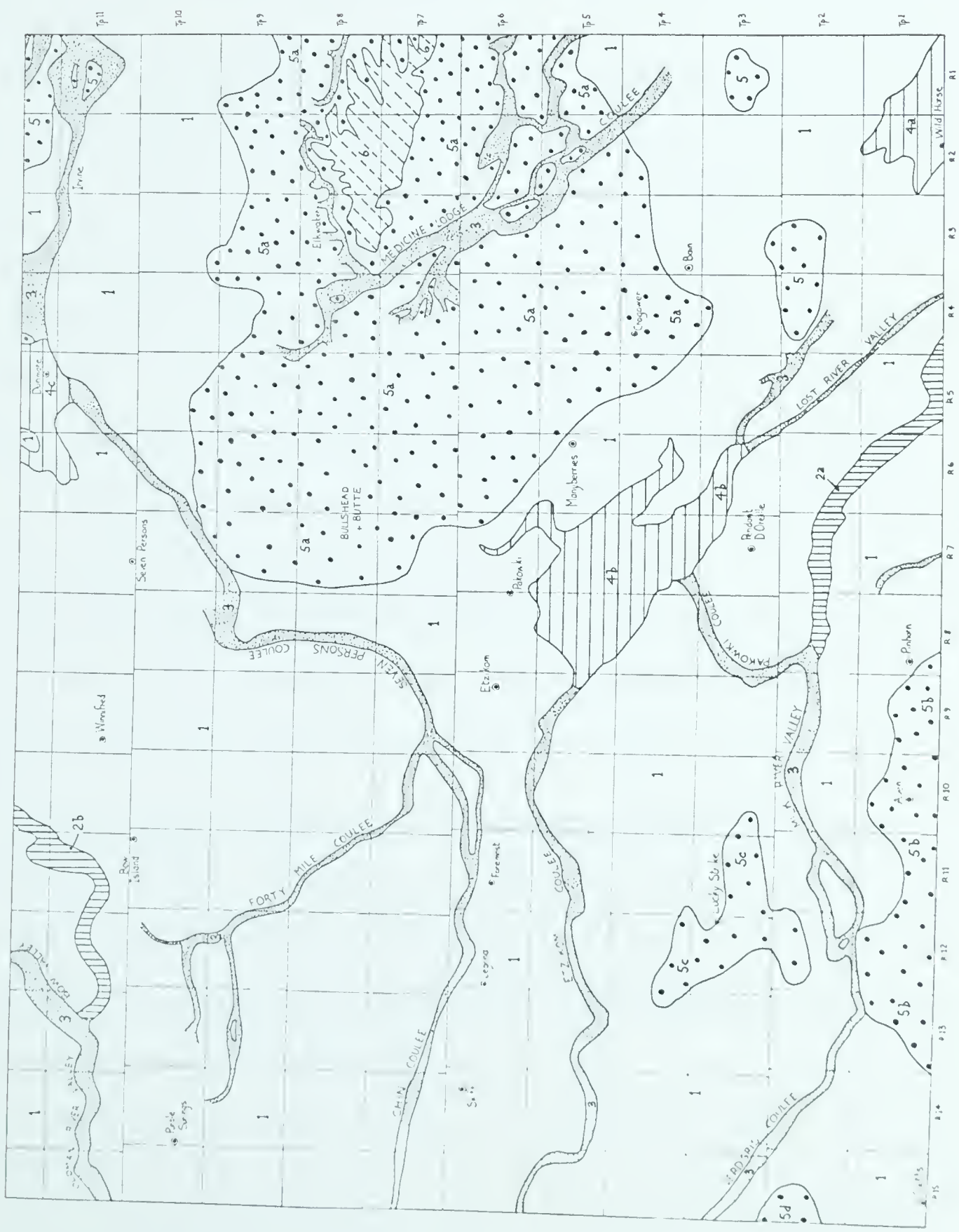


Figure 3. Physiographic units of the Foremost-Cypress Hills area, Alberta

Upland areas

For the purpose of this report, an upland is a relatively elevated area possessing considerably greater relief than the adjacent plains. A conspicuous change in slope marks the junction of the plains and upland areas. Usually, this occurs at an elevation of 3000 to 3500 feet. The survival of these upland areas is largely due to their interstream position (in preglacial times), structural elevation, and resistance to erosion.

The well-dissected Cypress Hills Upland descends northward from the plateau to about 3500 feet above sea level. Westward, it falls to about 3000 feet, just west of Bulls Head Butte, and southward, it drops to approximately 3200 feet at Bain, by the Canadian Pacific Railway line.

The Sweet Grass Hills of northern Montana lie just south of the 49th Parallel, but their foothills extend northward into the map-area, occurring south of the Milk River, between ranges 9 to 13, where they reach a maximum height of 4200 feet.

The Lucky Strike Upland, whose summit is 3300 feet above sea level, is situated north of the Milk River and south of Etzikom Coulee.

The eastern end of the Milk River Ridge extends into the map-area at an elevation of 3500 feet and is located to the southwest of Verdigris Coulee.

Till plain

Almost three-quarters of the area is a till plain of undulating to rolling relief. Generally speaking, north and west of the Cypress Hills the regional slope is towards the northeast. Thus Coutts is 3468 feet above sea level, Foremost 2915 feet, and Seven Persons 2480 feet above sea level. In the southeastern part of the area the regional slope is to the southeast.

Lacustrine plains

There are three lacustrine plains in the area: all are of Pleistocene age, and, except for Lake Pakowki, no longer contain water. The largest is Lake

Pakowki, just over 2800 feet above sea level. Lake Wild Horse, situated in the southeastern corner, is approximately at the same elevation. To the north, Lake Medicine Hat is less than 2400 feet above sea level.

River channels

The continuity of the plains surface is broken by a system of deeply entrenched coulees that are often more than a mile wide and 100 feet deep (e.g. Verdigris, Etzikom, and Chin coulees). Most of them are dry today or contain misfit streams. Similar channels surround the Cypress Hills (Plate 2).

Canyons

In two places, the above-mentioned channels become so entrenched and steep-sided that the term "canyon" is more appropriate. The Milk River Canyon extends downstream from the junction of Pakowki Coulee and the Milk River Valley. It is over 400 feet deep and one and a half miles wide, and is cut entirely into bedrock. The South Saskatchewan River occupies a canyon more than 300 feet deep and one mile wide. It likewise is cut largely into bedrock (Plate 3). The relative age of these canyons is clearly shown on the topographic map (Foremost Sheet). The sides of Milk River Canyon are well dissected, especially the southern side (Plate 4). The South Saskatchewan Canyon, on the other hand, has few subsidiary gullies.

Drainage

Apart from the internal drainage basin centred on Lake Pakowki, two great river systems, the Missouri and South Saskatchewan, drain the region (Figure 4). Milk River, Lost River, Sage Creek and Lodge Creek all flow into Montana to join the Missouri River by which their water is eventually conducted to the Gulf of Mexico. To the northwest, the Oldman and Bow rivers join to form the South

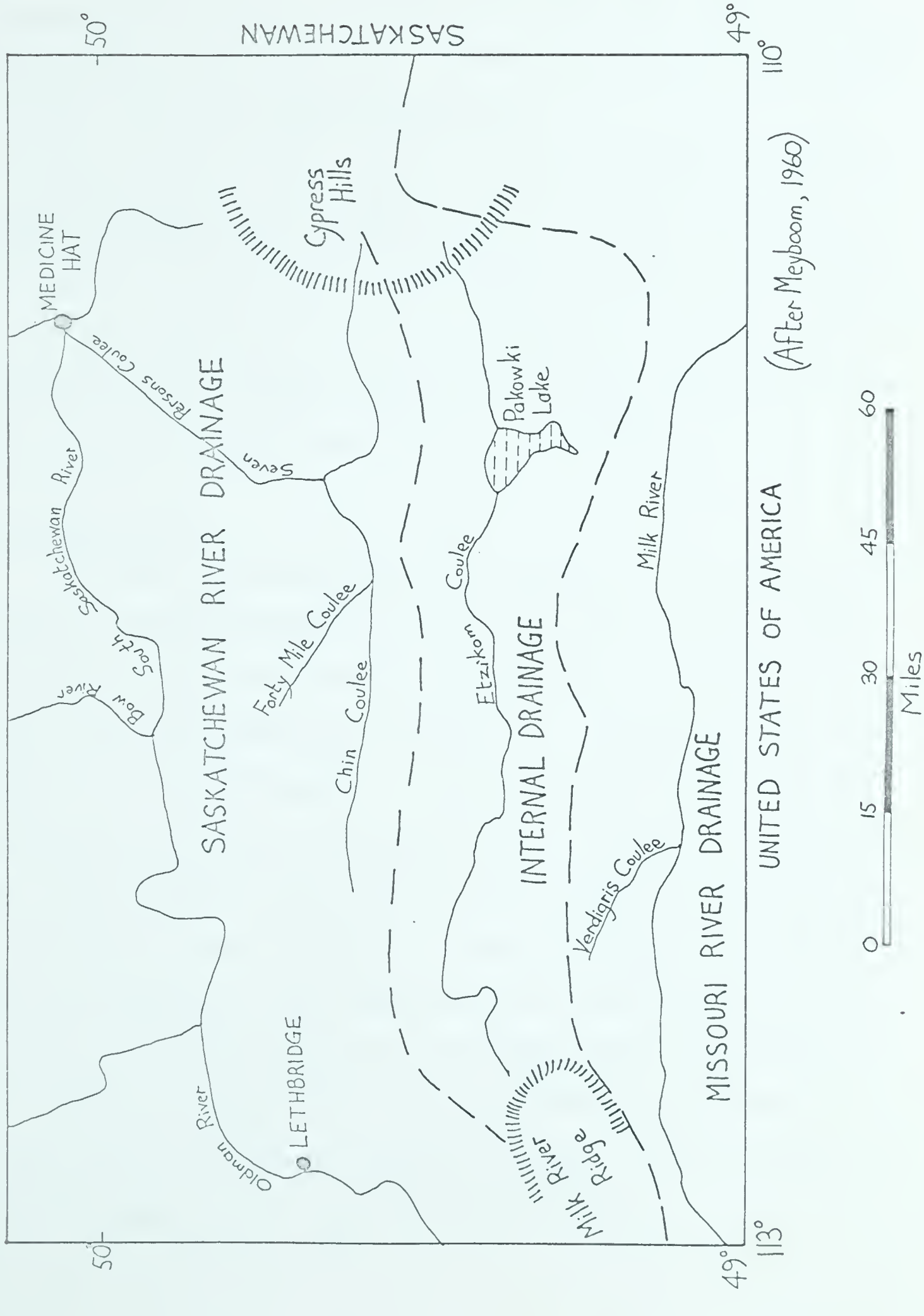


Figure 4. Drainage systems of southern Alberta

Saskatchewan River into which drain the north-flowing Seven Persons, Bullshead, and Ross creeks (Foremost Sheet). The South Saskatchewan River unites with the North Saskatchewan below Prince Albert, Saskatchewan, and their combined waters flow into the Hudson Bay by way of the Nelson River.

Drainage features readily show that the area was glaciated. To mention a few, Medicine Lodge Coulee and Milk River Canyon cut across a preglacial divide; the entrenched coulees were obviously not formed by the present streams that occupy them, but by meltwater run-off from ablating ice sheets; some channels have side-hill positions (Seven Persons Coulee), others form lobate patterns and must mark retreatal stages of an ice lobe (small channels west of Forty Mile Coulee).

Missouri Drainage Basin

The northern limit of the Missouri Drainage Basin extends eastward from the southern slopes of Milk River Ridge to a position south of Lake Pakowki, where it turns north to the Cypress Hills and then east again along the Cypress Hills Plateau (Figure 4). The only perennial stream of this basin, in the map-area, is Milk River. The latter enters the area at township 2, range 15, strongly meandering, incised into the Milk River sandstone, and flowing (eastward) along the axis of its preglacial valley. Verdigris Coulee, now dry and some 50 feet above the Milk River, enters the Milk River Valley from the northwest at township 2, range 14. Further east, Deadhorse Coulee (Black Coulee) opens into the Milk River Valley at both ends and represents another abandoned channel. At township 2, range 10, the Milk River begins to leave its preglacial valley, flowing east to Pakowki Coulee and then southeast, through the Milk River Canyon, into Montana. All streams south of the Cypress Hills Plateau contain water only during early summer.

South Saskatchewan Drainage Basin

The southern margin of the South Saskatchewan Drainage Basin extends from Milk River Ridge to the Cypress Hills (Figure 4). The major rivers are the Oldman, Bow, and South Saskatchewan, the latter flowing out of the area in a northeasterly direction. The Chin--Forty Mile--Seven Persons coulee system lies in this basin but presently conducts very little water. Most of the streams flowing north from the Cypress Hills occupy preglacial valleys, but some follow meltwater channels. Thus, Gros Ventre Creek flows in a preglacial valley from the northwestern corner of the Cypress Hills to Norton where it makes a right angle turn to the east to flow along a meltwater channel and join Ross Creek (Foremost Sheet). East of Ross Creek, there is a small internal drainage basin, Mackay Creek draining into a series of shallow lakes north of the map-area.

Lake Pakowki Internal Drainage Basin

The Lake Pakowki Internal Drainage Basin is sandwiched between the South Saskatchewan and Missouri basins and occupies a linear belt of land, longitudinally bisected by Etzikom Coulee. Although this coulee is the main channel of the basin, it contains only a small stream that flows into the now almost dry Lake Pakowki.

During the greater part of Pleistocene time no internal drainage existed in the map-area. Meltwater flowed eastward along Etzikom Coulee debouched into Lake Pakowki and from here was conducted south via Pakowki Coulee to the Milk River. With the cessation of meltwater flow, the southern part of Pakowki Coulee became plugged by Milk River alluvium (Williams and Dyer, 1930), reversing the gradient of the coulee. This fact, coupled with thick morainal deposits north of Lake Pakowki, resulted in the formation of the internal drainage basin.

Climate, Vegetation and Soils

Southeastern Alberta has a semi-arid climate with hot summers and bright, cold winters. Although a considerable distance east of the Rocky Mountains, the area is influenced by warm chinook winds at irregular intervals throughout the year. Southwesterly winds prevail during the winter months but are less frequent in summer (Kendrew and Currie, 1955).

The mean annual temperature is 43°F. From November to March the mean monthly temperature is below 32°F. and during the summer months (May to September) it exceeds 50°F. In winter the temperature has been known to fall to -50°F. whilst in summer, temperatures of over 105°F. have been recorded.

The mean annual precipitation is 13 inches. Generally, the eastern half of the area receives less than the western, and, in the extreme southeast, the annual precipitation may not reach 10 inches. The upland areas attract more precipitation than the surrounding prairie. In the Cypress Hills the mean annual total often exceeds 18 inches.

Except for the Cypress Hills, the area is covered by a typical prairie flora of grasses and sagebrush. Trees are absent on the prairie but sometimes are found along the coulees associated with willow. The amount of precipitation received in the Cypress Hills region is sufficient to support tree growth. Forest clothes the northern escarpment and many of the coulees are heavily wooded at the eastern end of the plateau. Lodgepole pine forms the principal tree growth, with aspen poplar, spruce, and black poplar occurring as local dominants. Grasses and low shrubs predominate on the plateau but there are a few wooded areas (Breitung, 1954).

Three soil zones are recognised in the Foremost-Cypress Hills area (Wyatt, et al., 1941). These zonal divisions are based principally on the colour of the soil profile which has developed as a result of certain soil moisture and vegetation conditions acting over a long period of time.

The brown soil zone covers about three-quarters of the map-area and corresponds to the bald prairie region. These soils have a shallow profile and the lime horizon is found about 12 inches below the surface. Dark-brown soils are found on the slopes of the Sweet Grass Hills and Cypress Hills. They have developed under more humid conditions and the depth to the lime horizon averages about 20 inches. Black soils occur on the Cypress Hills Plateau and surrounding slopes down to an elevation of about 4000 feet. The lime horizon is found at depths of 24 to 30 inches below the surface. Grey-wooded or podsolised soils are found under heavy tree growth and moist soil conditions. Such soils exist in the wooded areas of the Cypress Hills.

CHAPTER III - PREGLACIAL PHYSIOGRAPHY

General Statement

Glaciation only slightly modified the preglacial physiography of the upland areas but considerably changed that of the lower tracts. Dawson (1885, pt. C, p. 140) fully appreciated this fact when he said:

> "The preglacial aspect of the country has been much rougher and more diversified than that which it at present presents ..... The glaciating agents have doubtless planed off many of these irregularities, and the surface has besides been deeply buried in its deposits ..... These have been laid down in greatest thickness in the pre-existing hollows and low tracts, and the general effect has been the filling up of the asperities and the production of wide areas of almost perfectly level prairie. That this has been the case has been evidenced by the fact that while some of the plateaux and ridges are but scantily covered with drift, the thickness shown in many of the river sections is over 200 feet."

In the present study, examination of the preglacial landscape was done by constructing a map of the topography of the bedrock surface, (Map 8), and another showing the areal variation in the thickness of drift (Map 9). In the western half of the area, most of the control was provided by seismic shot hole logs. The bedrock surface contours in the eastern half, however, were drawn up from information obtained from field observations, a few water well and seismic shot hole logs, and the Foremost Sheet (72E N.T.S.).

Topography of the Bedrock Surface

Land forms

The bedrock surface topographic map shows land forms that were formed in glacial as well as preglacial time. The glacial features are quite distinctive, however, and may be readily recognised. They are all meltwater channels (for only the erosional features would be recorded on a bedrock surface topographic map). Never more than two miles wide, they have steep, sometimes vertical walls and cut across

upland areas, often breaching preglacial divides. Thus, the preglacial divide from the Cypress Hills to the Sweet Grass Hills is breached by no less than four meltwater channels (Milk River Canyon, Lost River Channel, Sage Creek Channel, and Medicine Lodge Channel). Similarly, the preglacial divide extending from Lucky Strike to Winnifred, is cut by the Etzikom, Chin, and Forty Mile channels. Some of the meltwater channels were later overrun by ice and completely filled with till (e.g. Granlea Channel township 8, range 9).

The preglacial valleys are usually very wide and have gently inclined slopes. The Ancestral Milk River Valley, for example, is over 10 miles wide in places. In addition, the tributary valleys invariably intersect the main channels at acute angles. The most conspicuous feature of the upland areas is their flat, plateau-like summits. The classic example of this is the Cypress Hills Plateau, but even the intrusive Sweet Grass Hills has a flat top (Williams and Dyer, 1930, p. 92). Likewise, the lower interfluvial areas possess broad, approximately horizontal summits. These surfaces are believed to represent remnants of old peneplains.

Erosional Surfaces

The significance of the elevated, commonly gravel-capped plateaux in the plains of western Canada was appreciated by McConnell as long ago as 1885. He realised that the plateau surface of the Cypress Hills was once the level at which rivers were flowing and that uplift and subsequent degradation had lowered the surrounding country some 2000 feet. Formed in Oligocene time, this particular surface is now 4800 feet above sea level at its western extremity in Alberta and 3700 feet as its eastern limit in Saskatchewan.

Collier and Thom (1917) studied the physiography of northeastern Montana and recognised several younger erosional surfaces. The oldest of these is now represented by isolated, gravel-capped plateaux, some 3200 feet above sea level at the

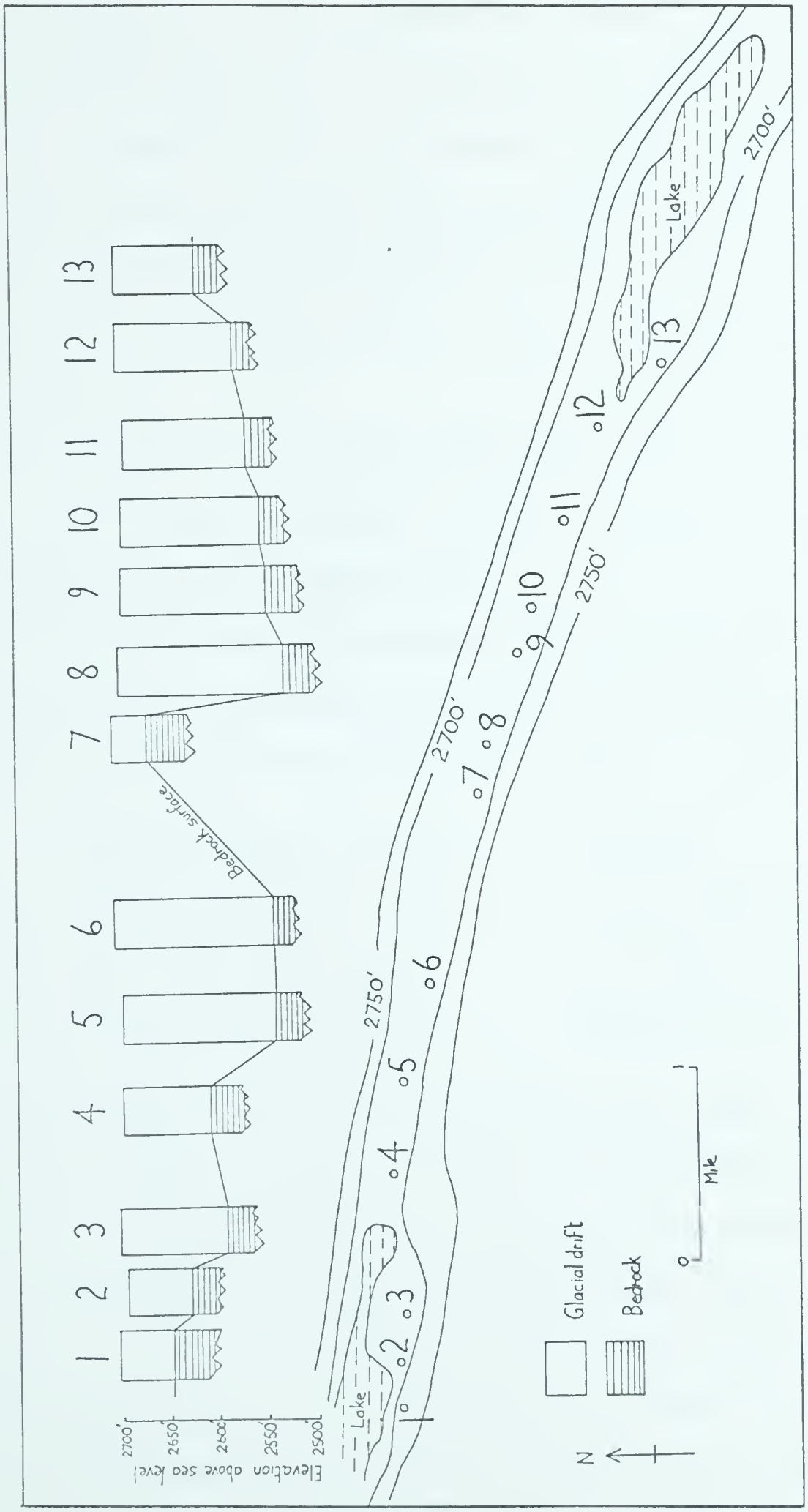


Figure 5. Geological section along Chin Coulee, northwest of Legend

The variation in thickness of glacial drift along Chin Coulee is related to the preglacial topography. Only the uppermost part of the drift is glacio-fluvial material which accumulated whilst melt-water flowed through Chin Coulee

western end of Boundary Plateau (about 109° West Longitude), and about 2600 feet near the town of Flaxville, Montana (about 105° West Longitude). Collier and Thom designated this erosional surface the Flaxville Plain and considered it to be of Miocene or early Pliocene age on the basis of vertebrate remains recovered from the gravels.

Below the Flaxville level, in northeastern Montana, there are extensive areas varying in elevation from 2500 to 3000 feet above sea level. Around Boundary Plateau much of this surface is highly dissected. A horse tooth, found in sediments on this surface (Collier and Thom, 1917, p. 182) indicates a late Pliocene or early Pleistocene age.

The wide valley bottoms, 100 to 500 feet below the late Fliocene or early Pleistocene level, represent the youngest erosional surface which is believed by Collier and Thom to be of late Pleistocene age.

Alden (1924, 1932) agreed with the erosional levels of Collier and Thom and recognised respective equivalents over much of the northern Great Plains of the United States. Alden's sequence of levels is given below.

Cypress Plain (No. 0 Bench)	Oligocene
Flaxville Plain (No. 1 Bench)	Miocene to early Pliocene
No. 2 Bench (or, Terrace)	Early Pleistocene
No. 3 Bench (or, Terrace)	Middle Pleistocene

In northeastern Montana the Flaxville Plain is 700 to 1000 feet lower than the eastern part of the Cypress Plain and Alden states that this difference increases to 1500 feet or more at the mountain fronts to the west. The vertical distance between the Flaxville Plain and the No. 2 Bench, east of 109° West Longitude, is generally 500 to 600 feet, but is only 100 to 300 feet near the Rocky Mountains. No. 3 Bench is about 100 to 500 feet below No. 2 Bench and represents the broad valley bottoms of the streams that cut into the No. 2 Bench. The Saskatchewan gravels and sands were deposited on the No. 3 Bench (Alden, 1924, p. 414).

Apart from the Cypress Plain (type section lies within map-area), can any of the other erosional surfaces mentioned above be recognised in southeastern Alberta?

The Saskatchewan gravels and sands floor the Ancestral Oldman and Milk River valleys. Thus, these valley bottoms correlate with the No. 3 Bench of Alden and were certainly formed before the area was invaded by Laurentian ice (Figure 6).

The divide between the Ancestral Oldman and Milk River drainage reaches 3200 feet above sea level at Lucky Strike in the south and about 2800 feet near Winnifred, to the north. This level most probably correlates with Alden's No. 2 Bench. The broad, flat-topped upland, southeast of Lake Pakowki, between Craigower and Pinhorn, reaches 3400 feet above sea level but is mainly around 3200 feet in elevation. This, likewise, is most probably a remnant of the No. 2 Bench. Collier and Thom (1917) show all the terrain surrounding the Cypress Hills, east of Range 4 and south to the 49th Parallel, as part of their Pliocene or early Pleistocene terrace (that is, the No. 2 Bench of Alden).

An elevation of about 3500 feet is indicated for the Flaxville Plain in the map-area if the surface gradient of this plain in northeastern Montana is projected due west along the 49th Parallel. This surface would naturally rise towards the Cypress Plain. Williams and Dyer (1930, p. 94) show the Flaxville Plain to be about 4000 feet in elevation immediately away from the Cypress Hills Plateau. The uplands around the Cypress Hills, however, are deeply dissected, and, if any remnants of the Flaxville surface remain they must be confined to small mesas and buttes (Figure 6).

Preglacial Drainage

Two major rivers, the Ancestral Oldman River and the Ancestral Milk River, flowed across the map-area in preglacial time. The former flowed in a northeasterly direction across the northwestern corner of the map-area, and received substantial-

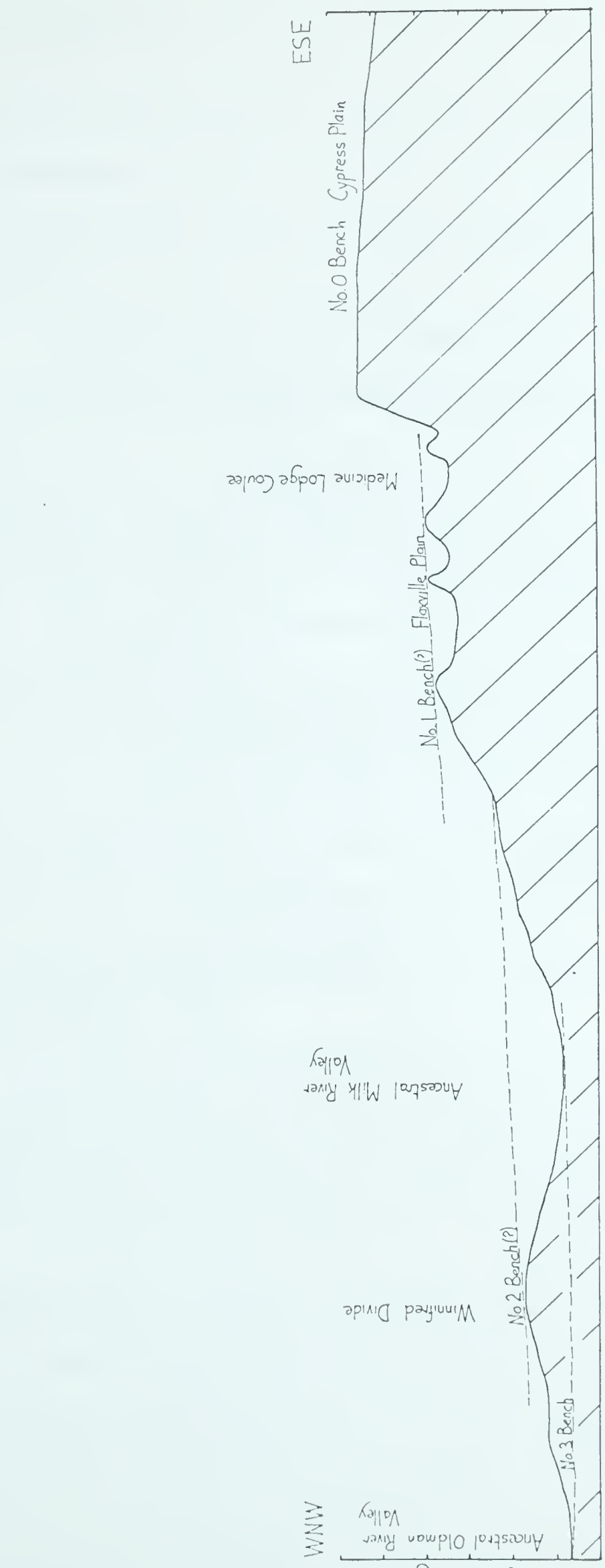


Figure 6. Topographic section showing erosional surfaces in the Foremost-Cypress Hills area, Alberta. Correlation with Alden's erosional surfaces is indicated.

sized tributaries from the south. Skiff and Foremost rivers were the largest of these: they joined each other just south of the present site of Bow Island, and their combined waters flowed north to meet the Ancestral Oldman River just outside the map-area (Figure 7).

The divide separating the Ancestral Oldman River drainage from the Ancestral Milk River drainage extended from Winnifred in the north to Lucky Strike in the south, where it turned west to run along the crest of the Milk River Ridge. At Masinasin, this divide was breached by headward erosion of the Skiff River, which may well have captured the waters of the Ancestral Milk River.

The Ancestral Milk River entered the map-area at essentially the same place as the present Milk River. It flowed eastwards between the Sweet Grass Hills Upland and the Lucky Strike Upland and gradually turned to the northeast to flow across the area now occupied by Pakowki Lake. From here, the Ancestral Milk River flowed north to Murray Lake where it turned to the northeast to flow across the present site of Medicine Hat. Tributaries of the Ancestral Milk River drained the northern and western slopes of the Cypress Hills as well as the eastern slopes of the Winnifred-Lucky Strike Divide.

The southeastern part of the map-area was drained by streams flowing to the southeast, and the divide that separated this drainage from that of the Ancestral Milk River ran from the Sweet Grass Hills to the Cypress Hills.

Figure 7 shows the relationship of the preglacial rivers of the Foremost-Cypress Hills area to those of central and southern Alberta. The Ancestral Oldman River joined the Ancestral Milk River some distance north of Medicine Hat, and the single river so formed then flowed into the Bow Channel. This channel then conducted the waters northeastwards across the province of Saskatchewan. The southeasterly flowing streams entered Montana and joined the Ancestral Missouri River which flowed eastward across northern Montana and then turned south in North Dakota to join the

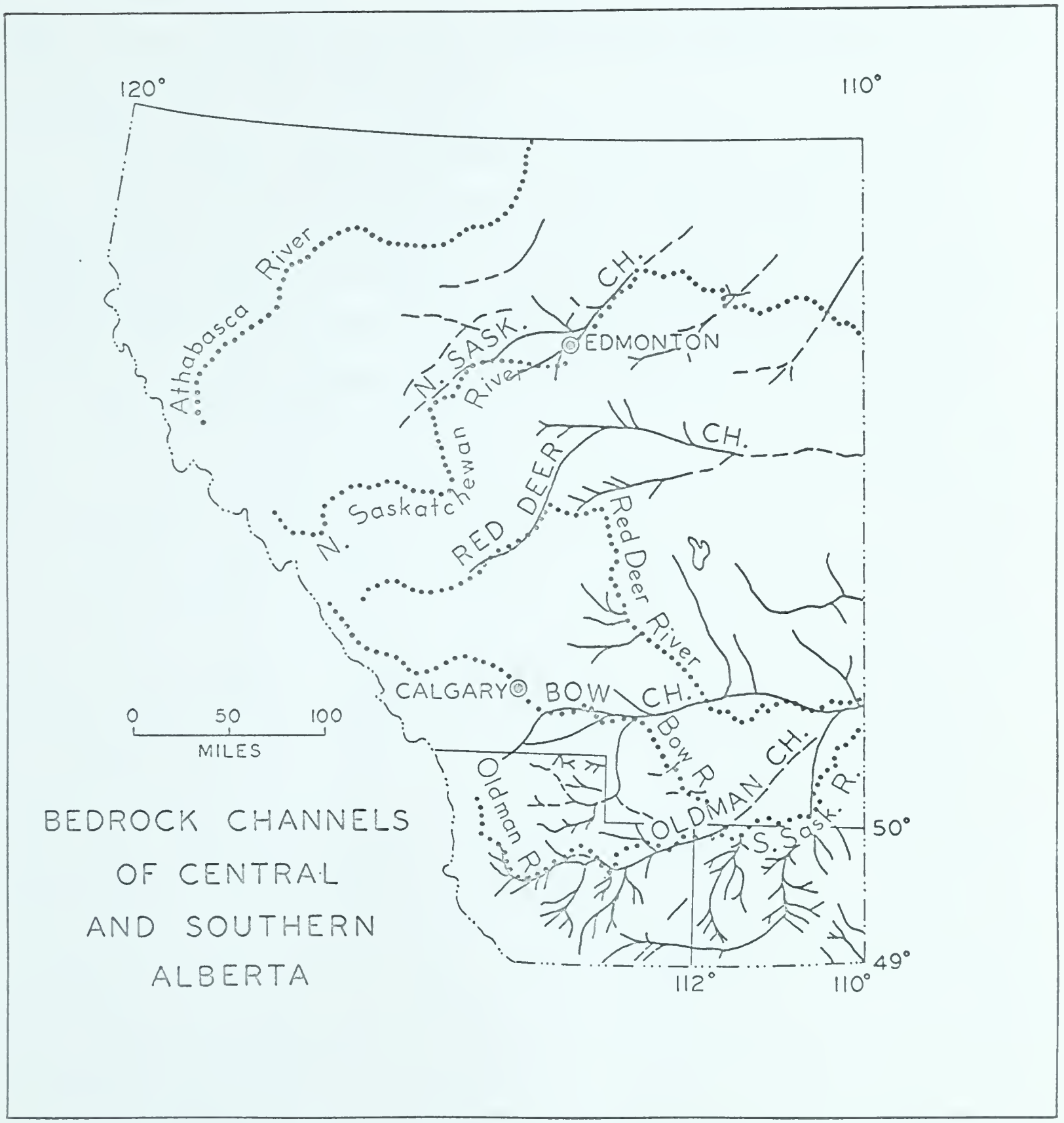


Figure 7. Bedrock channels of central and southern Alberta

Sources of information:

Central Alberta; Stalker (1960), Farvolden (1963).
Southwestern Alberta; Geiger (written communication, 1964)
Southeastern Alberta; present report

Mississippi River. These waters eventually flowed into the Gulf of Mexico. Earlier the Ancestral Missouri River flowed northeastwards, across the northwestern corner of North Dakota, into Canada. Whilst flowing on the No. 2 Bench level (Alden, 1924), however, its course was diverted to the south by the Kansan Laurentian ice sheet (Alden, 1924, 1932; Howard, 1960).

The preglacial landscape, therefore, was one of large rivers flowing in broad, mature valleys and draining mainly to the north and northeast. Except for the Cypress Hills Plateau, the interfluvial areas were considerably dissected. The present youthful aspect of rivers, the south-flowing Milk River, the buried valleys and many of the badland areas are all products (directly or indirectly) of glaciation.

CHAPTER IV - BEDROCK GEOLOGY

Introduction

Several surveys of the bedrock geology of the Foremost-Cypress Hills area have been carried out. Dawson (1885) and McConnell (1885) did the pioneer work. Later, Dowling (1917), Williams and Dyer (1930), and Russell and Landes (1940) worked out and described in detail the stratigraphical succession and structure. The bedrock geology of the Cypress Hills area in Saskatchewan has been studied by Fraser, et al. (1935), Russell (1948), Furnival (1950), and Kupsch (1956a).

The map of the bedrock geology included in this report is essentially that of Russell (1940) with minor alterations and additions. These include modification of the boundary between the Oldman and Foremost formations near Granlea (township 8, range 9) as a result of the discovery of a buried channel (see topography of the bedrock surface); reinterpretation of the deformation localised around Bullshead Creek (northwest of the Cypress Hills); addition of small outliers of Cypress Hills formation north of Battle Creek and structural data obtained from Mr. L. Lindoe (Medicine Hat Brick and Tile Company), later publications, and aerial photographs.

A review of the local bedrock geology is very relevant to the study of the surficial geology, if only for the following reasons:

(1) most of the mass of glacial drift, in the Western Plains of Canada, is local bedrock material (Bayrock, 1962; this report);

(2) knowledge of the distribution of rock-types in the bedrock is a necessary prerequisite for the recognition of indicators, which are valuable tools in determining ice-movement directions;

(3) surficial materials may resemble bedrock materials; and,

(4) enquiry into the genesis of some land forms and drainage patterns demands a knowledge of the geological structure.

Stratigraphy

Apart from the Tertiary conglomerate and sandstone that caps the Cypress Hills, Upper Cretaceous rocks - a succession of sandstone and shale units with minor bentonite - cover the entire surface of the map-area.

Alberta formation

The Alberta formation underlies the whole map-area, but is seen at the surface only in two places; the north flank of the West Butte of the Sweet Grass Hills, in township 1, range 12, and northwest of the Cypress Hills, in NW 1/4 of section 32, township 8, range 4. The last locality was discovered by Mr. L. Lindoe (Medicine Hat Brick and Tile) in 1962 and confirmed by Dr. J. Wall (Research Council of Alberta). This formation is composed of dark-grey, marine shale with minor sandstone beds, and is approximately 1700 feet thick.

Milk River formation

Outcrops of this formation are restricted to the southwestern corner of the map-area, the beds being best exposed along Milk River and Verdigris Coulee. The lower part of the Milk River formation consists of about 100 feet of light-coloured, massive sandstone underlain by 50 or more feet of beds transitional to the Alberta shale. The upper part was deposited in freshwater, is 130 feet or less in thickness and consists of sombre, grey shale and buff sandstone, with thin lignite and ironstone beds.

Pakowki formation

The Pakowki formation is exposed west and south of Lake Pakowki. It is of marine origin and consists of dark grey shale, with occasional thin beds of sandstone, siltstone, and bentonite. The lower contact is commonly marked by thin beds of grey to black chert pebbles and the upper contact with the overlying

ERA	PERIOD	EPOCH	FORMATION
CENOZOIC	QUATERNARY	PLEISTOCENE	glacial deposits
	TERTIARY	OLIGOCENE	Cypress Hills
		PALAEOCENE	Ravenscrag
MESOZOIC	CRETACEOUS	UPPER CRETACEOUS	Frenchman
			Battle
			Whitemud
			Eastend
			Bearpaw
			Oldman
			Foremost
			Pakowki
			Milk River
		L. CRETACEOUS	Alberta

Figure 8. Stratigraphic column of the Foremost-Cypress Hills area, Alberta

Foremost beds is transitional. The thickness of the Pakowki formation increases from west to east, being about 500 feet in the southeast.

Foremost formation

The Foremost formation is exposed over the greater part of the western half of the map-area: to the east it is seen along the Milk River Canyon and South Saskatchewan River. It contains much shale, but is predominantly arenaceous. The Foremost beds are a mixture of brackish water and freshwater deposits, and consist of shaly silts, sandstones, coal seams, ironstone concretions and silicified oyster shell beds. The thickness is about 370 feet in the north, nearly 500 feet in the central district, and about 270 feet in the southeast.

Oldman formation

Good exposures of Oldman continental beds occur up Lost River Valley from the International Boundary, and in the badlands east of Manyberries, west of Bulls Head Butte, and south and east of Irvine (Township 11, ranges 2 and 3). The formation is exposed mainly in the eastern half of the map-area, but outliers do occur as far west as township 11, range 12. The typical rocks are light-coloured, argillaceous sandstone, interbedded with green, sandy shales. Coal seams occur in the upper part of the formation. The coarser beds commonly show crossbedding and are lenticular. The thickness of the formation in borings near Eagle Butte is 480 feet.

Bearpaw formation

The Bearpaw formation borders the Cypress Hills on the south, west and north. Extensive outcrops occur southeast and east of Manyberries, on the west side of Bulls Head Butte, along Ross Creek south of Irvine, and also in Gros Ventre Creek. The formation consists mainly of dark grey, greenish grey, and chocolate brown,

fissile, marine shales with occasional sandy beds. Spheroidal ironstone concretions and bentonites are common. The thickness exceeds 630 feet near Manyberries and is about 830 feet in borings near Eagle Butte.

Eastend formation

This formation is confined to the Cypress Hills area, where it occupies a belt at the foot of the main escarpment. It is made up of massive, medium-grained sandstones, dark shales (in part marine), and carbonaceous beds and is about 400 feet thick.

Whitemud formation

Outcrops of the Whitemud formation are few, occurring mainly to the west of the Cypress Hills, around Eagle Butte and Fly Lake. Some exposures exist at Graburn Gap to the east. The uppermost beds of the Eastend formation in most places pass transitionally into the overlying Whitemud formation, which consists of sandstones, white clay, and kaolinised sandstones interbedded with carbonaceous shale and lignite. In Saskatchewan the Whitemud formation is about 50 feet thick, but is thinner in Alberta.

Battle formation

The distribution of the Battle formation corresponds closely to that of the Whitemud formation. In many places both formations have been partly or entirely removed by erosion prior to the deposition of the Frenchman beds. Lithologically, the Battle formation consists almost exclusively of dark, purplish grey, bentonitic shale and tuff. The thickness is variable, but approaches 30 feet in places.

Frenchman formation

Apart from a few isolated outliers near Eagle Butte and Fly Lake, the Frenchman beds, in the map-area, are confined to the Cypress Hills, where they underlie the

upper part of the hills. This formation consists essentially of thick, massive or coarsely crossbedded, medium-grained sandstone with rare coaly beds, and is over 100 feet thick.

Ravenscrag formation

The Ravenscrag formation is exposed along the escarpment of the Cypress Hills. It is a completely non-marine sequence, composed of thinly bedded, fine-grained sands, silts, and shales with numerous coal beds and lignitic laminae. The upper limit of the formation is an erosional surface, so thicknesses are variable, but exceed 100 feet in the map-area.

Cypress Hills formation

This formation underlies all of the summit region of the Cypress Hills. As developed in Alberta, it is composed almost exclusively of conglomerate with very minor lenses of sand and thin bentonite beds. The pebbles and boulders are mainly of quartzite, argillite, and chert, but volcanic porphyry and granite do occur. At the western end of the Cypress Hills, the conglomerate is 25 feet thick, and increases to over 50 feet at the Alberta-Saskatchewan border.

Structure

The southern Alberta plains are situated on a broad, northerly-plunging anticline known as the Sweet Grass arch. The Foremost-Cypress Hills area lies east of this arch, so the dominant dip direction of the beds is to the east and northeast. Many subsidiary folds are associated with the Sweet Grass arch and these are described in detail by Russell (1940, pp. 102-124). Nose- and dome-like structures are developed around the igneous intrusions of the Sweet Grass Hills.

Several points of interest concerning the bedrock structure arose while

studying the surficial geology. These are listed below; the first two being brought to the writer's attention by Mr. L. Lindoe.

(1) Northwest of the Cypress Hills, in the Bulls Head Creek district (townships 8 and 9, ranges 4 and 5), the bedrock is highly disturbed. Russell (1940, p. 124) attributed this deformation to large-scale slumping, but the discovery of the Alberta shale at the surface in NW 1/4 of section 32, township 8, range 4 (a vertical displacement of over 3000 feet), discredits this hypothesis. A pronounced gravity anomaly exists in this area and suggests that the structural elevation of the Alberta, Milk River, and Pakowki(?) formations is due to the emplacement of an igneous body at depth, probably synchronous with the Sweet Grass intrusions in northern Montana.

(2) Along the southern slope of the Cypress Hills the uppermost 50 feet of strata have been deformed by movement, under gravity, on underlying clay beds. The low-angle gravity sliding is also probably responsible for the large fissures and small tensional faults in the Whitemud beds exposed in the clay pit at Fly Lake (SW 1/4 of section 20, township 8, range 3).

(3) The nature and orientation of some surficial lineaments in the map-area cannot be explained by glaciation. These non-glacial lineaments show up on aerial photographs as thin, dark lines. They may be several miles long, intersecting, or subparallel (Figure 8). It is believed that these lineaments represent fault or joint traces that have been reflected through the unconsolidated glacial drift (Kupsch, 1956b; Kupsch and Wild, 1958; Mollard, 1957, 1958; Haites, 1960; Barton, 1962). This reflection occurred when adjustment took place along the faults (Kupsch and Wild, 1958), possibly due to differential isostatic rebound (Barton, 1962).

Some lineaments, however, are much more conspicuous and have obviously been formed over large faults in the bedrock. An example is seen in township 11,

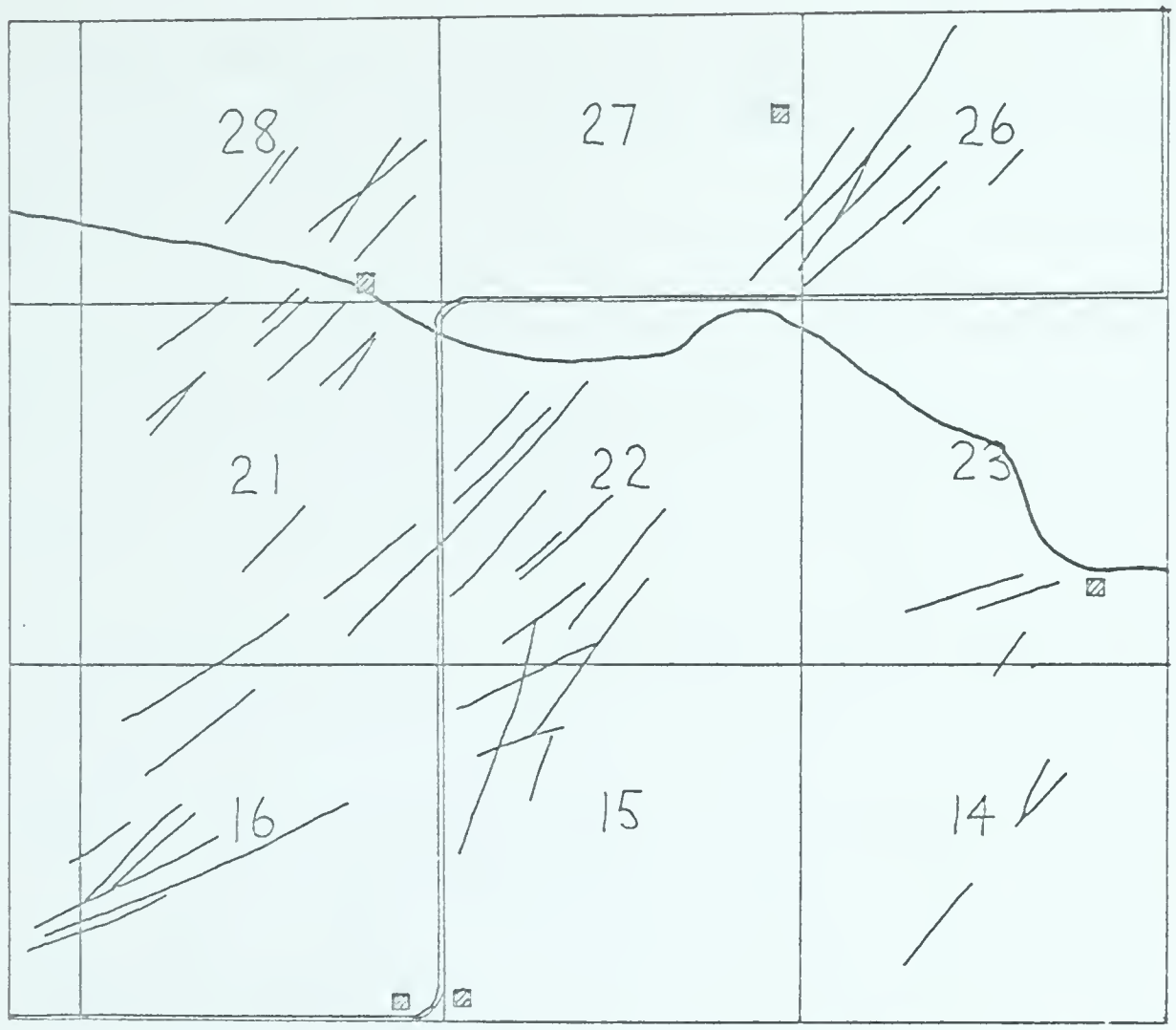


Figure 9. Structural lineaments showing through glacial drift, north of Seven Persons

range 15, where the fault trace is marked by a trough, some 200 yards wide (Plate 5). The course of the South Saskatchewan River is controlled in part by this fault.

CHAPTER V - GEOMORPHOLOGY

Introduction

Preglacial land forms have already been discussed. This section deals with those features formed since the first incursion of Laurentian ice into the map-area. For the purpose of this discussion, these land forms are classified into three major groups.

(1) Glacial land forms include those features formed inside the margin of the ice sheet.

(2) Proglacial land forms include those features formed along the edge and outside, or away from, the ice margin.

(3) Postglacial land forms include those features formed after the complete disappearance of the last ice sheet.

The terminology of glacial land forms at present is not clearly defined. In this report, the writer has taken the nomenclature proposed by Gravenor and Kupsch (1959) as his main guide, and the terms used by other workers are given at the appropriate place.

Where an alignment of glacial land forms exists, the line passing through these land forms, showing the orientation and lateral extent of their alignment, is known as a "glacial lineament". Most of these lineaments are not observable at ground level, but can readily be seen on aerial photographs (Plate 10). A study of their trends has proved very helpful in determining the directions of ice movement and in elucidating the glacial history (Map 1).

Glacial Land Forms

Ground Moraine

Gently undulating to undulating ground moraine covers about 1250 square miles, or 20 per cent, of the map-area, and occurs mainly in the northern half of the area (Map 1). It has a constructional topographic expression with a local relief seldom exceeding 10 feet. Numerous undrained depressions are characteristic (Plate 6).

Flint (1957, p. 131) defined ground moraine as that moraine having low relief devoid of transverse linear elements. As pointed out by Gravenor and Ellwood (1957, pp. 7-8), this definition does not hold true for much of the ground moraine in western Canada. Here transverse elements - small till ridges and aligned knobs - do occur in morainal areas of low relief, especially where the latter grades into hummocky disintegration moraine (Plate 7).

The glacial drift varies in thickness from 5 to over 100 feet in areas where ground moraine is developed. It consists predominantly of clayey till, the greater part of which is made up of local bedrock (see Chapter VI). Till is a nonsorted, nonstratified sediment deposited by a glacier. The upper part of the drift in areas of ground moraine commonly contains irregular lenses and pockets of sand and gravel, and, on the surface, small patches of lacustrine sand, silt and clay are occasionally present.

The undulatory surface and compact nature of the till suggest that ground moraine was largely formed at the base of a moving glacier. Till deposited in this way - from drift in transport in the base of a glacier - is called lodgment till (Flint, 1957, p. 120). A thin blanket of ablation till, however, invariably overlies the lodgment or basal till but does not obscure the undulating character of the ground moraine. Ablation till consists of debris that was transported within or upon the ice

and was deposited on the ground surface as the enclosing ice melted (Flint, op. cit.). Inclusions of stratified drift are not uncommon in ablation till and show that meltwater transported some of the drift for short distances during the settling process.

Hummocky Disintegration Moraine

Hummocky disintegration moraine covers about 670 square miles of the map-area and occurs mainly in the upland areas; that is, around the Cypress Hills, the foothills of the Sweet Grass Hills, and on the northern part of the preglacial Winnifred Divide (Map 1).

This morainal land form is characterised by an irregular "knob-and-kettle" topography with steep-sided depressions, and both closed (circular, oval, and irregular) and linear ridges. Where the local relief of hummocky disintegration moraine is greater than 25 feet, the above elements are well developed and the till is thick, certainly more than 50 feet (Gravenor and Kupsch, 1959, p. 50; Ellwood, 1960, p. 25); but only knobs and occasional linear ridges are present in areas of hummocky disintegration moraine with a local relief of less than 25 feet, and here the till is considerably thinner (Plates 8 and 9). In the map-area, moraine plateaux, which are relatively flat areas usually slightly higher than the surrounding knobs, are quite rare in the hummocky moraine whose local relief varies from 15 to over 50 feet. Knobs, kettles and ridges are haphazardly arranged and no trends are discernible. As mentioned above, hummocky disintegration moraine usually grades laterally into ground moraine, but sometimes the contact is sharp.

Terms used by other workers to designate areas of knob-and-kettle topography include dead-ice moraine (Christiansen, 1956; Bayrock, 1957, 1960; Gravenor and Ellwood, 1957); knob and kettle moraine (Stalker, 1956); hummocky moraine (Hoppe, 1952; Christiansen, 1959; Stalker, 1960, Ellwood, 1960); hummocky ground moraine (Parizek, 1961); and ablation moraine (Flint, 1957).

Hummocky disintegration moraine is composed mainly of till that is very

similar in character to the till of ground moraine. The surface ablation till, however, is generally thicker and more widespread than in ground moraine areas. Pockets, lenses, and stringers of clay, silt, sand and gravel occur in the till and commonly show "collapse" structures typical of ice-contact deposits. Sometimes whole knobs are made up of sand and gravel, but usually the latter just caps the till knobs.

It is generally accepted that hummocky disintegration moraine formed in areas where blocks of ice stagnated during deglaciation, but the way in which this hummocky topography originated is still a subject of controversy. Two major hypotheses have been proposed: the ablation or "let-down" theory and the "squeezing-up" theory.

In the "squeezing-up" theory the hummocky topography is believed to have formed underneath the ice by the squeezing of debris into basal cavities caused by meltwater. The drift could be squeezed up into these cavities because it was soaked with water and therefore in a plastic state. The weight of the ice itself exerted the necessary pressure. Hoppe (1952) is a proponent of this theory and Stalker (1960) believes this mechanism is responsible for the hummocky moraine in western Canada.

The ablation theory, which is generally favoured by most geologists working in western Canada, envisages englacial debris gradually accumulating on the surface of the ice, and, due to differential melting of the ice at the surface, let down irregularly on the ground. Gravenor and Kupsch (1959) present a strong argument for this ablation mechanism, but believe that squeezing-up of till into openings at the base of the ice may have taken place to some extent. The writer believes that the ablation mechanism best explains the morphology, lithology and distribution of the hummocky disintegration moraine in the Foremost-Cypress Hills area.

Hummocky disintegration moraine is largely restricted to the upland areas (see above), closely associated with end moraines (Map 1), and clearly formed near the ice margin. Woldstedt (1954, p. 95) noted this and suggested that hummocky

moraines may take the place of true end moraines.

As the glacier moved uphill, obstructed flow commenced. Some of the basal debris was carried into an englacial or superglacial position along thrust planes (Figure 10). In this way the marginal belt of ice was covered with a thick mantle of debris. This ice then stagnated, but it did not downwaste evenly. Debris-coated ice melted more slowly than the naked ice. The hollows so formed were eventually filled with debris and topographic inversion of the ice surface resulted (Gravenor, 1955). This inversion was probably repeated several times before the debris finally came to rest on the ground surface as a hummocky mass.

This process explains the presence of deformed beds of lacustrine and glacio-fluvial materials in the till of hummocky disintegration moraine, and the gradation of this morainal unit into ground moraine is seen to be due to the gradual decrease of englacial and superglacial debris away from the ice margin - that is, away from the zone of obstructed ice flow (Figure 10).

End Moraine

The most extensive land form in the map-area is end moraine, which covers some 1700 square miles, or 27 per cent of the area. End moraine surrounds the Cypress Hills Upland, is well developed around Lake Pakowki and covers almost the entire southwestern quadrant of the map-area (Map 1).

Flint (1957, p. 131) defined an end moraine as a ridgelike accumulation of drift built along the margin of an ice sheet. End moraines in the Foremost-Cypress Hills area have an elongate, linear or curvilinear outline, are usually several miles wide, and consist of a series of aligned ridges that parallel former positions of the ice front. Some end moraines in this area formed at or close to the ice front, but the major end moraines (especially hummocky end moraine) formed along a wide marginal zone of the glacier - chiefly by stagnation of fractured, debris-clogged ice.

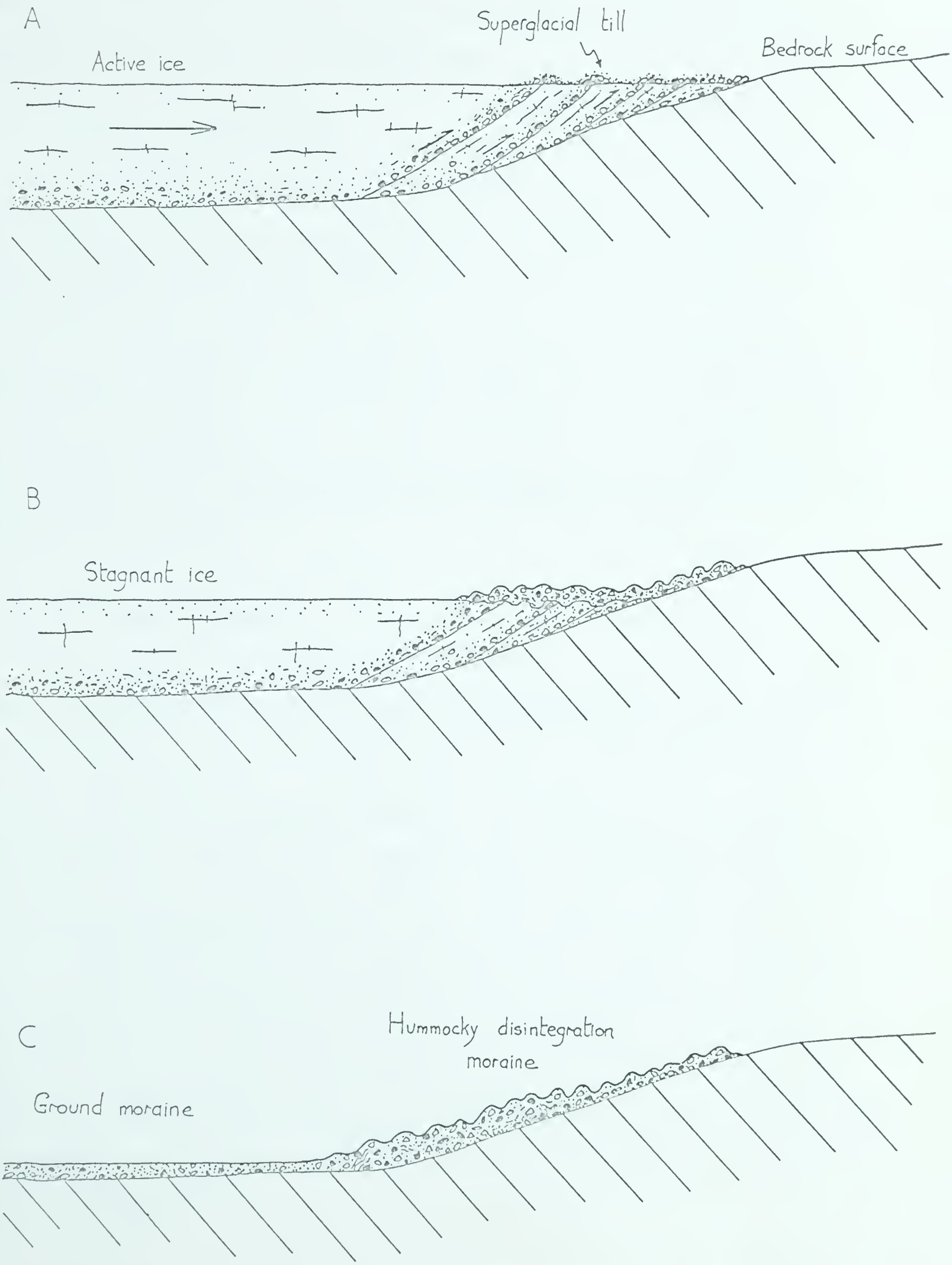


Figure 10. Diagrammatic sections showing stages in the formation of hummocky disintegration moraine

Three morphologically distinct types of end moraine exist in the map-area: hummocky end moraine, ridged end moraine, and washboard moraine. (The first two are only differentiated on the one inch to one mile maps).

(1) Hummocky end moraine

Hummocky end moraine resembles hummocky disintegration moraine in all respects except that it occurs in linear or curvilinear belts rather than in irregular masses, and the knobs, closed ridges and linear ridges are aligned in a common direction (Plate 10). This alignment is most probably the result of ice-fracture control. Fractures developed at the margin of the active glacier and persisted when the glacier became stagnant. This marginal belt of stagnant ice then separated along the old fracture lines and ablation drift became concentrated in the linear ice depressions so produced.

(2) Ridged end moraine

Ridged end moraine (called "end moraine" on the one inch to one mile maps) is characterised by a system of sub-parallel, discontinuous, generally arcuate ridges, composed mainly of till - very stony in places - with minor amounts of gravel and sand. Knobs are usually present but closed ridges are rare or absent (Plate 11). The local relief is variable, but is generally less than that of hummocky end moraine. East of Lake Pakowki, it approaches 25 feet, and in the southeastern corner of the area, the local relief is less than 15 feet. At the former locality, the main ridges are usually 200 to 300 yards apart (Plate 11), and the thickness of the till varies from 20 to 50 feet. To the west of Lake Pakowki, where the till is much thicker ridged end moraine grades into hummocky end moraine (Manyberries Sheet). The main ridges most probably mark retreatal positions of the ice front; some of the smaller ridges may be crevasse fillings.

(3) Washboard moraine

A series of small, parallel till ridges, which are generally referred to as washboard moraine, are well developed north of Seven Persons and south of the Milk River (Plate 12). These ridges are 2 to 10 feet high, 100 to 300 feet apart, and vary from a few yards to over a mile in length.

Minor end moraines, minor recessional ridges (Christiansen, 1956) and swells and swales (Gwynne, 1942) are other names that have been given to this morainal form.

The origin of washboard moraine is uncertain, but the gradation into hummocky and ridged end moraine, and the lobate patterns described by the ridges, clearly show that washboard moraine is formed near the ice margin, with the ridges paralleling former positions of the ice front. Gwynne (1942, p. 206) visualised washboard moraine as being formed by periodic retreat and readvance of the live glacier front, pushing previously deposited ground moraine into ridges. He suggested that the ridges were formed annually. Elson (1957, p. 1721) studied washboard moraines in Manitoba and concluded that the ridges were deposited subglacially at the base of thrust planes in the ice. Gravenor and Kupsch (1959, p. 55) agreed with Elson's idea and regarded the preservation of the ridges as the result of ultimate stagnation of the ice.

Linear Disintegration Ridges

Linear disintegration ridge is a general term proposed by Gravenor and Kupsch (1959, p. 53) for a ridge that originated during stagnation or near-stagnation of the ice. Debris that had accumulated in crevasses on the ice surface or fissures at the base of the stagnant ice, would be left as linear ridges on the ground when the ice disappeared.

In some areas these constructional ridges are composed chiefly of till with or without included pockets of sand and gravel; in other places stratified material predominates. Linear disintegration ridges are straight or slightly arcuate, vary in height from 5 to over 40 feet, and in length from a few yards to several miles. Their most common orientation is normal or parallel to the direction of ice movement.

Flint (1928, p. 415) proposed the term "crevasse filling" for the ridges that were composed of stratified material. Christiansen (1956, p. 15) used this term for ridges composed of till, but Gravenor (1956, p. 10) preferred the term "till crevasse filling". Sproule (1939, p. 104) noted similar features in the Cree Lake area, Saskatchewan, which he called "ice-crack moraine". Another term is "till and till-cored esker ridges" (Stalker, 1960b, p. 13).

In the Foremost-Cypress Hills area, linear disintegration ridges are largely composed of till where associated with hummocky disintegration moraine, hummocky end moraine, and ground moraine. The best examples, however, are made up of stratified gravel and sand and are found at the northwestern corner of Lake Pakowki (Plate 13), and beside Lost River.

Special circumstances are responsible for the formation of the linear ridges at Lake Pakowki. For a short period, the outer margin of a stagnant ice block lay beneath the waters of Glacial Lake Pakowki. Glacio-fluvial material transported along Etzikom Coulee entered Glacial Lake Pakowki, and, in part, was deposited on the submerged ice surface. This sediment filled up crevasses in the ice. Soon after, the latter became emergent, finally melted, and left a series of arcuate, subparallel, occasionally intersecting ridges composed entirely of sand and gravel (Plate 13). The sediment is rudely sorted; in the west the ridges contain large cobbles, further east fine gravel predominates and grades eastward into sand.

In the Lost River district, the ridges lie parallel to the direction of ice

movement. They were formed by meltwater concentrating sand and gravel into longitudinal crevasses in the stagnant ice. This sediment was let down as the ice melted and it eventually settled on the ground to form ridges.

Drumlins and Drumlinoid Ridges

Many of the linear ridges in the Lost River district have been "drumlinised" (Plate 14). This occurred when a localised reactivation of the glacier shaped the stratified sediment in the crevasses into the streamline form characteristic of drumlins. On the maps, such features are called "drumlinoid ridges"; they always parallel the direction of ice movement and their stoss end is "up-ice". In places, classical drumlins have been formed, over 50 feet high and composed entirely of gravel and sand (Plate 14).

A swarm of very similar drumlins occur north of Dead Horse Coulee (township 2, range 11). They were probably formed by ice readvancing over a small outwash plain (Plate 15).

A point of interest with regard to the origin of drumlins and drumlinoid ridges in the map-area is that they all occur in areas where the regional slope was away from the ice front. It is possible that during the latter stages of stagnation, when the ice was "warm", actual flowage under gravity occurred, remoulding the englacial debris into streamline forms.

Kames

Holmes (1947, p. 248) proposed the following definition for the term kame: "A kame is a mound composed chiefly of gravel or sand, whose form has resulted from original deposition modified by any slumping incident to later melting of glacial ice against or upon which the deposit accumulated."

Mounds of stratified drift are scattered throughout the map-area, but are more abundant in areas of hummocky disintegration moraine and hummocky end moraine.

The best examples, however, occur in Glacial Lake Medicine Hat (township 12, ranges 4 and 5), and in the southeastern part of the area, where kames are associated with eskers, drumlins and linear disintegration ridges (Plate 14).

Eskers

An esker is a long narrow ice-contact ridge, straight or sinuous, and composed chiefly of stratified drift. A system of eskers, aligned parallel to the direction of ice movement, occurs in the southeastern corner of the map-area (Map 1 and Wild Horse Sheet). Straight and sinuous types are present (Plates 16 and 17); the former are indeed spectacular examples.

The best developed esker (Plate 16) extends from the Manyberries Range Station southeastward to Wild Horse, a distance of over 12 miles, and continues into Montana. In places it rises 50 feet above the surrounding prairie level and is over a mile wide for a considerable part of its length. Linear, circular, and irregular kettles pit the esker and a few channels, now abandoned, cut right across the ridge. Sections in the occasional gravel pit show crossbedded gravel and sand that indicate transportation to the southeast, that is, in the direction of the regional slope.

The presence of channels cutting across the above-mentioned esker ridge, now abandoned and unrelated to the present drainage, suggests that the eskers were formed by deposition of glacio-fluvial material in subglacial tunnels. Superglacial streams eroded into the esker's sediment as the ice surface downwasted, and dry gullies were left in the esker ridge when the ice finally disappeared. Linear disintegration ridges draped over the esker ridge point to the same origin. The kettles were formed when buried blocks of ice melted and caused subsidence of the overlying sediment, but, those along the flanks of the ridge are more likely related to the loss of the confining walls of ice.

Collapsed ice-contact stratified drift

Areas of stratified drift, with an undulating to rolling topography, are mapped as "collapsed ice-contact stratified drift". Flint (1957, p. 152) called such areas "collapsed masses".

"A blanket of stratified sediment was deposited upon thin ice and let down on to the ground as the ice melted. Variations in thickness of ice and of sediment combined to give the collapsed sediment an unsystematic undulatory upper surface." (Flint, 1957, p. 152)

Two areas of collapsed masses have been mapped; both are in meltwater channels. One lies in the Medicine Lodge Channel and the other in the meltwater channel west of Green Lake (Green Lake Sheet).

Flutings

Flutings are narrow, straight, parallel ridges and grooves, composed of till or bedrock. They are oriented in the direction of ice movement, and occur in swarms and not as single isolated ridges or grooves (Plate 4).

Flutings are present on the Lucky Strike Upland, the foothills of the Sweet Grass Hills south of the Milk River, on the preglacial divide southeast of Lake Pakowki, and in the area just north of Milk River and east of Pakowki Coulee (Map 1). The first three localities are upland areas, where the drift is very thin and bedrock commonly exposed at the surface. At the last locality, the flutings are entirely in drift.

The relief on flutings is usually only a few feet; the length of the ridges and grooves, however, is commonly more than a mile. Hence, it is difficult to discern flutings from the ground, but they show up very clearly on aerial photographs.

Flutings in the bedrock, south of the Milk River (Plate 4), show that glacial erosion is the dominant factor in their origin, but the exact mechanism whereby flutings are created is still a matter of conjecture.

Bedrock upland veneered with drift

As the name implies, this is not a specific glacial land form, but essentially a dissected bedrock upland area which has been slightly modified by the deposition of glacial drift. The surface expression of this drift is constructional in places, but is more commonly controlled by the bedrock surface. The drift is usually thin, except in the preglacial valleys, and bedrock exposures are numerous.

Proglacial Land Forms

Outwash Plains

Outwash plains cover only a restricted part of the Foremost-Cypress Hills area. This is because the regional slope over much of the area was into the glacier and not away from it. During deglaciation, therefore, meltwater was forced to flow along the ice margin, carrying glacio-fluvial material with it. Wherever the slope of the land was away from the glacier, outwash plains or aprons resulted (Map 1).

The largest outwash plain occurs in the southeastern corner of the map-area and covers about 100 square miles. It is flat to undulating and is composed of thin stratified gravel, sand and silt, with the underlying till and bedrock commonly showing at the surface. Stagnant-ice features (linear disintegration ridges, kames and eskers) sit on this plain together with a few drumlins composed of stratified gravel and sand (see above).

The southern slopes of the Lucky Strike Upland are covered by thin outwash gravel and sand. Drumlins composed of glacio-fluvial material, are present on this plain too.

A few miles to the northeast of the Lucky Strike Upland, a fan-shaped patch of outwash sand, about 15 square miles in area, overlies till and narrows northwards to a small interlobate system of kames. A superglacial stream must have flowed between

two ice lobes, here, and built up an outwash apron in front of the ice. The slope of the land was away from the glacier at this locality, which overlies the south-sloping north bank of the Ancestral Milk River (Map 8).

Small outwash aprons exist in front of the end moraines north of the Cypress Hills (Elkwater Sheet).

The remaining outwash plains or aprons are associated with meltwater channels, and occur in the northwestern quadrant of the map-area (Map 1). Although the regional slope was into the ice throughout this area, over sites of pre-glacial valleys, the slope was occasionally away from the ice margin, and at these locales, outwash aprons were formed. The largest of these (and the second largest in the map-area) is the sandy outwash plain, 60 square miles in area, south of Purple Springs and Grassy Lake (townships 9 and 10, ranges 13 and 14).

Loess Plain

The loess plain is co-extensive with the unglaciated Cypress Hills Plateau and adjacent slopes to the south, and covers about 120 square miles (Map 1). The loess overlies the weathered, oxidized cap of the Cypress Hills conglomerate, varies in thickness from 1 to 8 feet, and contains numerous quartzite pebbles from the underlying Cypress Hills conglomerate that were elevated into the loess by frost action (Plates 1 and 18). The resultant fabric of the loess resembles that of till (that is, unsorted), but no erratic pebbles are present. An interesting point about these displaced pebbles is that their long axes are usually in a vertical position, clearly indicating post-depositional changes in the loess as well as the underlying Cypress Hills conglomerate. Indeed, the uppermost 6 feet of the Cypress Hills conglomerate has been deformed by frost action, as is evidenced by the presence of deranged pebbles (Figure 11) and involutions (Plate 18, B; Sharp, 1942; equivalent to "festoons" of Schafer, 1949).

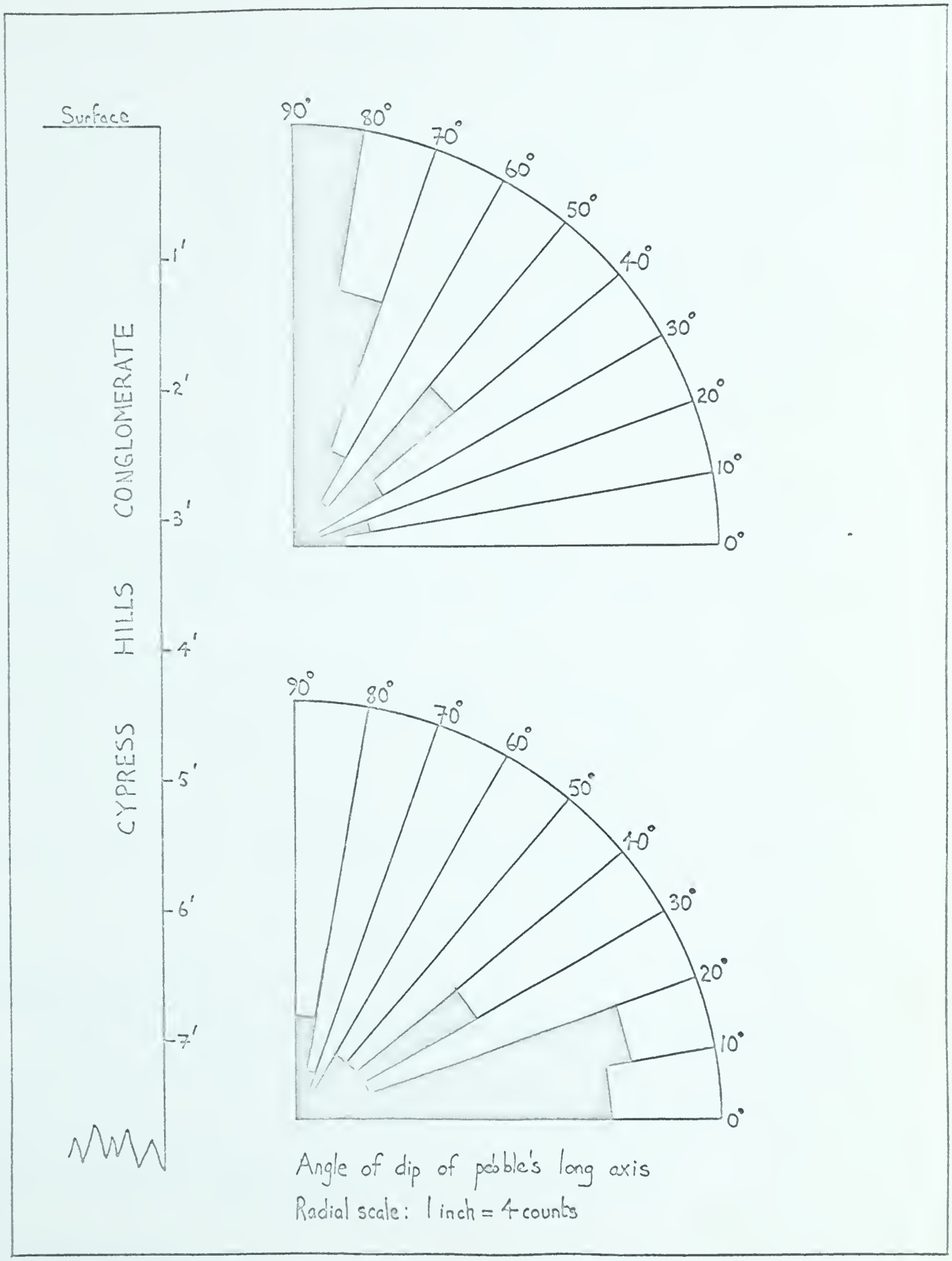


Figure 11. Rearrangement of pebbles in the upper part of the Cypress Hills conglomerate - the result of frost action

The textural variation of the Cypress Hills loess suggests northerly prevailing winds during the period of loess deposition (Figure 12). These winds picked up part of the finer fraction of the glacial drift and deposited some of it on the unglaciated Cypress Hills Plateau. That this was the case is shown by the presence of mineral species in the loess that are common in the neighbouring drift but absent in the underlying Cypress Hills formation (e.g. fresh green hornblende - see Figure 12 and Chapter VI). The loess at the northern end of the plateau is coarse-grained, and, in places, over 50 per cent sand (Figure 25). The winds that transported this material, therefore, must have been strong, and were most probably katabatic in nature, coming off the nearby ice sheet.

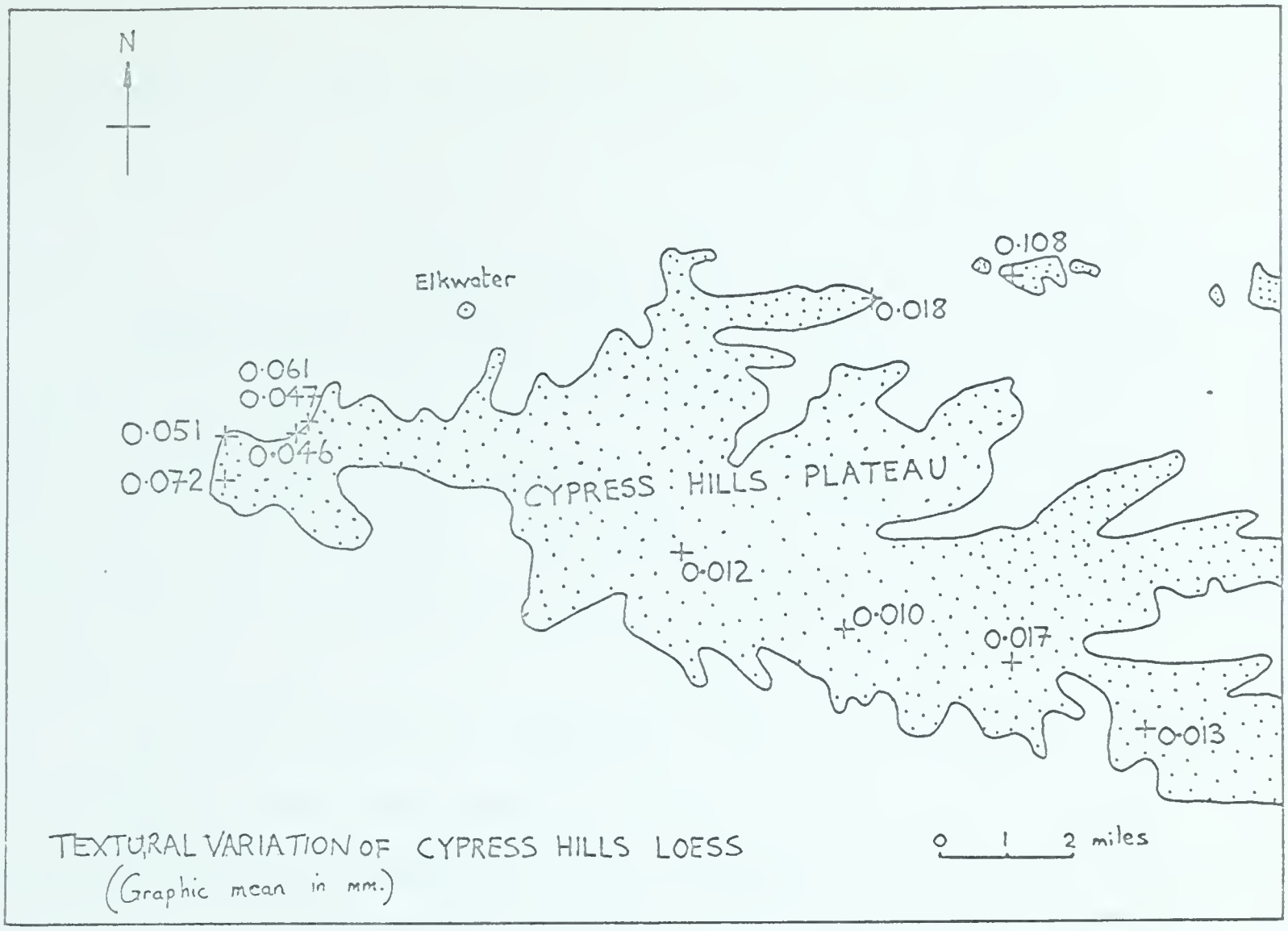
The deformation of the Cypress Hills conglomerate and the loess by frost action must have occurred when the area was in a periglacial environment. Low temperatures, strong winds, and many fluctuations across the freezing-point at certain seasons characterise such an environment (Sharp, 1942). With the mean annual temperature less than 0°C., perennially frozen ground developed, and the sediment in the active layer - the surface layer which is repeatedly subjected to fluctuations across the freezing-point - was deformed as a result of the repeated formation and subsequent thawing of ice. In the Cypress Hills, the active layer was about 6 feet thick.

Glacial Lake Basins

Lacustrine deposits cover about 500 square miles of the map-area and everywhere overlie preglacial topographic lows (Maps 1 and 8). The glacial lakes may be classified into two groups: the proglacial lake that ponded against the ice margin as the latter retreated down regional slope and the superglacial lake.

Proglacial lakes

As the regional slope was into the glacier over much of the area, proglacial lakes are common. In addition to small patches of lacustrine sediment on



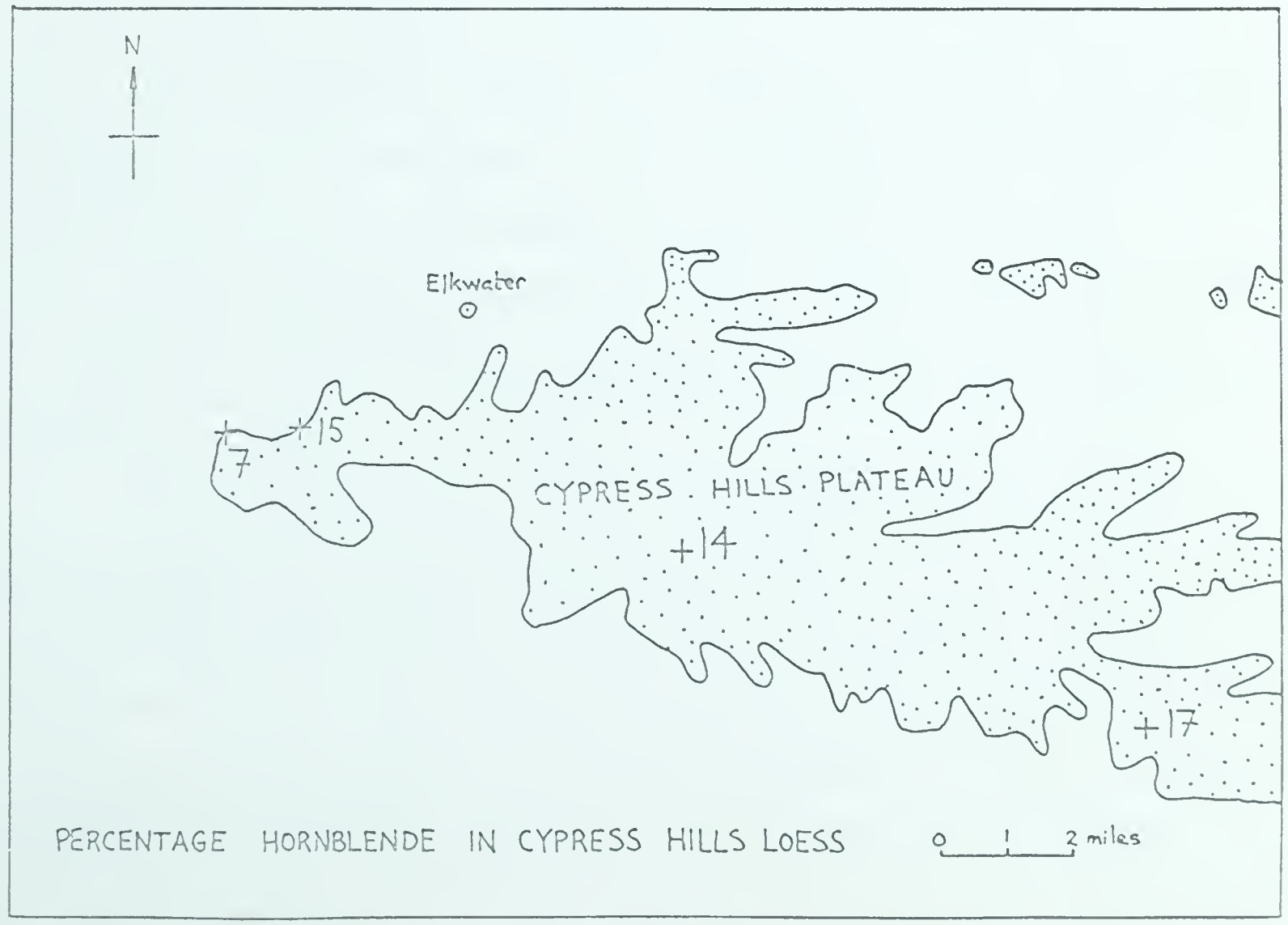


Figure 12. Textural variation and percentage hornblende in Cypress Hills loess

ground moraine, four large proglacial lakes occur in the Foremost-Cypress Hills area.

(1) Glacial Lake Pakowki

Glacial Lake Pakowki Basin occupies the centre of the map-area, covers about 120 square miles, and overlies the Ancestral Milk River Valley. To the northwest, the topography is hilly and the dominant sediment-type is sand and gravel (see linear disintegration ridges). This changes into a flat plain in the southeastern part of the basin, where a few feet of clay overlies sand. The thickness of the lacustrine sediment is not known.

Two deltas project into the lake basin. The larger one lies in front of Etzikom Coulee (Plate 13). It is composed of sand and gravel and the "cut and fill" structure, or large-scale festoon crossbedding, indicates deposition in shallow water. The other delta is situated just west of the point where Irrigation Creek enters Lake Pakowki (Map 1 and Manyberries Sheet). It is much sandier and contains transported and in situ remains of Equisetum sp., together with fragmental bison bones. The presence of Equisetum sp. indicates deposition in shallow water, and some of its remains were collected for a C^{14} date, but the writer has not received the result as yet.

Only one strandline of Glacial Lake Pakowki was found (section 19, township 3, range 6). It is marked by a sandy beach deposit that is just over 2900 feet above sea level.

Glacial Lake Pakowki was formed when meltwater accumulated in front of the ice margin as the latter retreated downslope towards the Ancestral Milk River Valley from the preglacial divide near Comrey (township 2, range 6). The earliest spillway was the Canal Creek Channel, just over 3000 feet above sea level (Map 1). This channel becomes an esker near Manyberries Range Station (township 2, range 4) and indicates that at this point the meltwater entered a subglacial tunnel in the

stagnant ice (Wild Horse Sheet). The next spillway to be used was the Lost River Channel at an elevation of approximately 2950 feet. With further backwasting of the ice front, the glacial waters found a lower outlet, the Pakowki Channel, which is less than 2900 feet above sea level. A considerable volume of meltwater entered Glacial Lake Pakowki via the Etzikom Ice-marginal Channel and left via the Pakowki Channel (Map 1).

It is most likely that proglacial lakes formed in this area during the retreat of earlier glaciers.

(2) Glacial Lake Medicine Hat

The southern part of the Lake Medicine Hat Basin lies in the map-area and covers about 25 square miles of township 12, ranges 5 and 6. It overlies the Ancestral Milk River Valley, slopes gently to the north, and contains "islands" of till and numerous kames (Map 1). The Seven Persons Channel enters this lake basin from the south (township 11, range 5), and, at this locality, the sediment is mainly sand and gravel. Sand predominates to the north and west, with silt and clay becoming more conspicuous in the extreme western part of the basin. The lake formed as a result of the confinement of meltwater to the lowland around Medicine Hat when drainage to the north was prevented by the glacier.

(3) To the east and west of Forty Mile Coulee, over an area of about 130 square miles, thin lacustrine sand, silt and clay overlie till (Map 1). These lacustrine sediments were deposited in a shallow proglacial lake that most probably drained via the Forty Mile Channel. The topography is flat to gently undulating and a sandy beach deposit occurs at section 16, township 8, range 12.

(4) An extensive area of lacustrine sand (160 square miles) occurs in the northwestern corner of the map-area and lies immediately above the now buried Ancestral Oldman River Valley. The sand is thin and the underlying till is

commonly exposed at the surface. The undulating to hummocky topography is related to the till and not the lacustrine sand, which is too thin to completely mask the hummocky till surface.

Superglacial lakes

Small patches of lacustrine sand, silt and clay are common in areas of hummocky moraine. These lacustrine deposits may be draped over till knobs or occur as deformed stringers in ablation till. They undoubtedly accumulated in shallow ponds on a stagnant ice surface, and were let down, together with the ablation till, on to the basal till as the ice melted away.

Glacial Lake Wild Horse

The northern part of the Lake Wild Horse Basin lies in the southeastern corner of the Foremost-Cypress Hills area, where it covers about 35 square miles (Map 1 and Wild Horse Sheet). Lake Wild Horse sediments are mainly sand and fine gravel with some silt, but in township 1, range 2, they are covered by recent alluvial and lacustrine silt and clay. In areas of recent sedimentation the topography is flat, but it is undulating and occasionally hilly over the remainder of the basin and in some places, the surface is pitted with kettles (Plate 19).

Unlike the above-mentioned glacial lakes, Lake Wild Horse formed in an area where the regional slope was away from the ice front, namely to the southeast. The esker that passes through Wild Horse dammed the glacial waters to the north. The last glacier to affect the southeastern part of the map-area became stagnant southeast of the preglacial divide that runs through Comrey (township 2, range 6). Superglacial and subglacial meltwater flowed to the southeast. Downwasting of the stagnant ice eventually resulted in the exposure of the eskers which were formed in the subglacial tunnels. Once above the ice surface, the eskers impeded the flow of superglacial meltwater, and, as a result, the superglacial Lake Wild Horse was

formed (Plate 19). Sand and fine gravel were deposited in this superglacial lake and let down on to the underlying till as the ice melted.

Deposits of both superglacial and proglacial lakes commonly contain invertebrate fossils. Several samples of fossiliferous lacustrine sediment were collected and submitted to Dr. R. Green of the Research Council of Alberta, who identified the fossils and commented on their ecological significance.

Fossiliferous superglacial lacustrine sediment was sampled at two localities. Figure 13 illustrates the geological setting of sample 3261 (see Appendix A for location of samples), and the fauna recovered from this sample is listed below.

Ostracoda

Limnocythere trapeziformis Staplin

Limnocythere staplini Gutentag and Benson

Ilyocypris gibba (Ramdohr)

Candona nyensis Gutentag and Benson

Candona renoensis Gutentag and Benson

Candona caudata Kaufman

Cyclocypris forbesi Sharpe

Cypris pubera Muller

Cyprinotus incongruens (Ramdohr)

Cypridopsis vidua (Muller)

Gastropoda

Stagnicola palustris nuttalliana

Stagnicola palustris (Muller)

Gyraulus cyclostomus Baker

Physa sp.

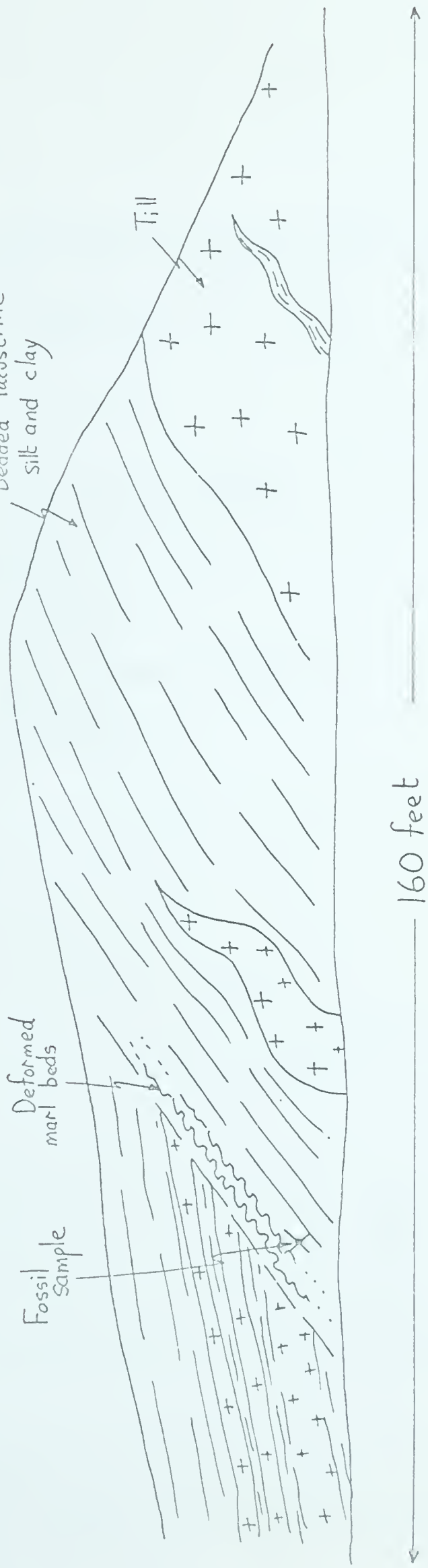


Figure 13. Geological setting of fossil sample 3261
lsd. 13, S. 28, Tp. 8, R. 4

Pelecypoda

Pisidium sp.

At the other locality, 3 feet of deformed sand and gravel with clay inclusions overlie till and contain the following fauna (sample 3663):

Ostracoda

Limnocythere trapeziformis Staplin

Ilyocypris bradyi Sars

Candona indigena Hoff

Candona renoensis Gutentag and Benson

Cypridopsis vidua (Muller)

Gastropoda

Stagnicola palustris (Muller)

Gyraulus sp. (intermediate between

G. altissimus (Baker) and *G. cyclostomus* Baker)

Physa sp.

Both these assemblages, together with the presence of marl, indicate shallow, cool but not cold lakes on the stagnant ice surface: the water probably warmed up to above 50°F. (10°C.) during the summer. In addition, the lakes were alkaline (that is, the same as present Alberta lakes) and surrounded by a moderate growth of vegetation.

Proglacial lake sediments were sampled at section 23, township 9, range 1 (sample 4961). Here 15 feet of lacustrine sand, silt, clay and marl overlie outwash

sand and gravel which is underlain by till. Fossils recovered from the lacustrine sediment include:

Ostracoda

Cyclocypris forbesi Sharpe

Potamocypris smaragdina (Vavra)

Cypridopsis vidua (Muller)

Candona nyensis Gutentag and Benson

Cyprinotus incongruens Ramdohr

Gastropoda

Succinea avara Say

Gyraulus altissimus (Baker)

Gyraulus cyclostomus Baker

Stagnicola palustris (Muller)

Physa sp.

Plants

Chara sp.

Chara sp., *C. incongruens*, *C. vidua* and marl indicate a shallow, cool lake, with moderate vegetation. It is most likely that this lake continued to exist after the disappearance of the glacier.

At section 18, township 10, range 5, 35 feet of bedded, in part fossiliferous, sand, silt and clay cover till and lie just south of a well-developed end moraine. Hence, it is presumed that these sediments were deposited in a proglacial lake. The

following gastropods were identified (sample 4262), being present mainly in the clay beds. Oddly, these are all terrestrial gastropods. They were most probably derived

Succinea avara Say

Vertigo modesta (Say)

Euconulus fulrus (Muller)

Vallonia gracilicosta Reinhardt

from nearby sediments. What is important, they indicate a damp to somewhat humid climate, certainly not dry, with no high summer temperatures and at least enough vegetation to offer shade close to the ground. In other words, a climate different from that of southern Alberta today.

Meltwater Channels

The term "meltwater channel" is here used to describe any channel that carried meltwater from the glacier. The meltwater channels of the Foremost-Cypress Hills area may be classified into three types: ice-marginal channels, consequent channels, and buried channels.

Ice-marginal channels are the most numerous type of meltwater channel in the map-area. Some are over one mile wide and 400 feet deep (Milk River Channel, Plate 3); others are less than 300 feet wide and only 10 feet deep (channels in townships 7 and 8, ranges 12 and 13; Plate 20). Most have steep-sided walls and a trenchlike cross profile, and, because their path was determined by the position of the glacier's margin, ice-marginal channels occasionally cut through preglacial hills and divides (Map 8). The Medicine Lodge, Verdigris, Milk River, Etzikom, Chin, Forty Mile, Seven Persons and South Saskatchewan channels are all ice-marginal channels. The broad upland of the preglacial Winnifred Divide diverted east-flowing meltwater to the south and southeast, along its western flank (Map 1). This explains the seemingly

anomalous orientation of the Forty Mile Channel. Because ice-marginal channels mark successive positions of the retreating ice front they are very helpful in unravelling the glacial history.

Consequent meltwater channels conducted meltwater away from the glacier, in the direction of the regional slope. Only a few of these channels occur in the map-area and most are situated south of the Milk River. Coutts Channel (township 1, range 15), Clarinda Channel (township 1, range 14), and Pinhorn Channel (township 1, range 7) all carried meltwater to the south, away from the glacier's margin (Map 1).

Both ice-marginal and consequent channels are cut in glacial drift and usually into the underlying bedrock as well (Maps 1 and 8; Figure 5). They are floored with recent alluvial and lacustrine silt and clay, which most likely cover glacio-fluvial material. Alluvial fans commonly extend into them.

Terraces are present along many of the channels. In the South Saskatchewan Channel they are carved in bedrock, their surfaces being covered by a veneer of glacio-fluvial material (section 15, township 11, range 12). Elsewhere, terraces are composed of glacio-fluvial sand and gravel. Examples occur in the Seven Persons Channel, just before it enters the Lake Medicine Hat Basin, and in the Medicine Lodge Channel (Green Lake Sheet). Along part of the Etzikom Channel (township 5, range 15) and Milk River Channel (township 2, ranges 10 and 11), the terraces are covered with till, indicating two phases of meltwater flow interrupted by a glacial advance.

A buried meltwater channel occurs just to the north of Crow Indian Lake (township 5, range 14) and another runs from the junction of Chin, Forty Mile and Seven Persons coulees, northwards through Granlea, to Murray Lake (Maps 1 and 8). The former channel was clearly part of the Etzikom Channel at one time. Both channels were filled with till when the glacier readvanced over them.

Spillways

Spillways are channels that were formed as drainage outlets of glacial lakes. Canal Creek Channel, Lost River Channel, Pakowki Channel and Milk River Canyon are spillways that drained Glacial Lake Pakowki (Map 1, Figure 32). Most of the water drained via the last two channels, which are, therefore, considerably larger than the others. Verdigris, Etzikom and Chin ice-marginal channels did drain glacial lakes to the west of the map-area (Stalker, G.S.C. map 41, 1962) and may be considered as ice-marginal spillways.

Eroded Plains

Severely eroded plains occur on the broad upland of the preglacial divide southeast of Lake Pakowki (Map 1). The drift is either thin or absent, badland is extensive, and ill-defined ice-marginal meltwater channels dissect the surface in places, especially south of the Milk River (Plate 21). Flutings extend across these channels and indicate an advance of the glacier over them; but little drift was deposited at this time, as the channels are still conspicuous and surface exposures of bedrock numerous. Till caps the higher areas, with gravel, sand, silt and clay occurring in the lower parts. In places the sand and silt has been transported by the wind for a short distance, producing dunes.

Postglacial Land Forms

River Valleys

Although the Milk, South Saskatchewan, Oldman and Bow rivers flow for the most part along old meltwater channels, they owe part of their present day appearance to postglacial erosion. The western stretch of Milk River (township 2, ranges 14 and 15), for example, meanders in a 50 feet deep, box-like canyon that was formed entirely in postglacial times. In addition, postglacial terraces occur

along the above-mentioned valleys which have been considerably deepened since the retreat of the last glacier.

North of the Cypress Hills, many postglacial valleys exist. They are all incised into the drift and bedrock and some are over 100 feet deep. In the southeastern part of the map-area, postglacial valley degradation was interrupted by a period of aggradation. Thus, Pinhorn Channel (township 1, range 7) has a fill of fine gravel, sand and silt, over 20 feet thick. Many of the valleys on the southeastern side of the preglacial divide that runs northeastwards through Comrey (township 2, range 6) are also aggraded. The valley at section 30, township 2, range 3 has a fill composed of gravel, sand, silt and clay from which a skull of Bison bison bison (Research Council of Alberta, catalogued under Westgate, 263) was recovered.

Dunes

Extensive dune development is found in two districts: the northeastern part of Lake Pakowki and the environs of the Oldman, Bow and South Saskatchewan rivers. Minor patches occur within the outwash plains (Map 1).

At Lake Pakowki, lacustrine sand has been blown on to the adjacent ground and end moraine by westerly winds. The sand extends on to the till as a group of lobes, convex to the east, within which occur blow outs, parabolic and transverse dunes (Plate 23). These thin, lobate sheets of sand, together with their superimposed dunes, are now stabilised by grasses, shrubs, and trees, but in places have been re-activated as a result of prolonged periods of drought.

Parabolic and longitudinal dunes, developed by west-south-westerly winds, are present in the northwestern corner of the map-area. They are composed of lacustrine sand which overlies the Oldman End Moraine. Some of the parabolic dunes have arms over a mile long and many of the longitudinal dunes are merely linked parabolic dunes (Plate 24). These dunes are now stabilised by vegetation.

The age of these dunes is not known exactly. They are certainly postglacial and may well have formed during the "climatic optimum".

Slump Areas

Landslides are common along many of the meltwater channels and postglacial valleys. This is particularly true in valleys where the streams have cut through the drift and penetrated the Bearpaw formation (Christiansen, 1959, p. 21) or shaly, bentonitic horizons of other bedrock formations. Landslides of the rotational slump-type are the most numerous; the slump blocks being topographically expressed as a series of sub-parallel ridges flanking the undisturbed valley walls. Examples occur along Medicine Lodge Coulee, the northern escarpment of the Cypress Hills, and along valleys to the north and south of the Cypress Hills (Elkwater Sheet).

CHAPTER VI - PETROGRAPHY OF GLACIAL DEPOSITS

General Statement

Only the tills and Cypress Hills loess are considered in this section. Textural and compositional studies have been made on the several till sheets in the map-area (Figure 32) in an attempt to provide physical criteria by which these till sheets may be differentiated and correlated. Field studies alone did not reveal how the sediment on the Cypress Hills Plateau originated: only after the texture and mineralogy had been examined did it become evident that this sediment was a loess.

As the figures and tables related to this section are numerous, they are placed at the end of this chapter in order to facilitate reading.

Petrography of Tills

The colour, texture, pebble composition, heavy minerals, and carbonate content of the tills were studied.

Colour

The colour of about 50 dry till samples was examined using the rock-colour chart distributed by the Geological Society of America (second edition, 1951). The most common colour is yellowish olive grey (5Y 6/2), but light olive grey (5Y 5/2 or 5Y 5/1) tills are present. The oxidised tills are dusky yellow (5Y 6/3), and yellowish brown (10YR 5/2 or 10YR 6/3).

Texture

Grain size analysis of the till samples was carried out according to the procedure given by Folk, 1961. The results are listed in Table I and the range in grain size of the till samples is shown in Figure 14. The latter figure consists of two

cumulative curves, one plotted from the highest values in Table I, the other from the lowest. The area bounded by these curves represents the range in grain size of the till samples. It is clearly seen that the tills are ill-sorted and contain an appreciable amount of clay.

The percentage sand (2.0 - 0.062 mm.), silt (0.062 - 0.002 mm.), and clay (<0.002 mm.) in the till samples were plotted on a triangular diagram and Figure 15 shows that most of the tills have a clayey loam to loamy texture. Clay loam is the average texture of tills overlying the Bearpaw formation: loam is the average texture of tills overlying the Oldman and Foremost formations.

After studying the distribution on a ternary diagram of more than 500 published till size analyses, Elson (1961) devised a grain size classification of tills. According to Elson's textural classification, most of the tills in the Foremost-Cypress Hills area have a clay, silty clay, or clayey silt texture (Figure 16). The point representing the average texture of tills overlying the Bearpaw formation lies on the boundary between the clay till and clayey silt till fields (Figure 16), whereas the point representing the average texture of tills on the Oldman formation lies within the clay till field. The latter tills, however, are coarser-grained than the former, but in Elson's classification they lie within a finer grain size field. Hence, the writer feels that Elson's clay till field is too large and his clayey loam field too small.

Elson also studied the relation of grain size distribution to the dominant rock types composing tills (1961, p. 12 and Figure 5). The grain size distribution of the tills that overlie the Bearpaw, Oldman, and Foremost formations - largely shale and siltstone with some sandy beds - agree closely with Elson's distribution for tills made up largely of such rocks (Figure 16).

Figure 17 shows the variation in texture of the tills with respect to the underlying bedrock. Tills on the Foremost formation are clearly coarser-grained than those on the Bearpaw formation, and the field embracing the tills on the Oldman

formation is placed more towards the sand end member than that of the tills on the Bearpaw formation. This suggests that the texture of the tills is controlled to some extent by the underlying bedrock.

A study of the areal variation of the texture of tills with respect to the bedrock was made by plotting the graphic mean (Folk, 1961, p. 44) of each till sample on a map of the bedrock geology (Figure 18 and Table I). The graphic mean is the average of the 16, 50, and 84 percentiles on the cumulative curve. The average graphic mean of tills overlying certain bedrock formations is given below:

tills overlying the Bearpaw formation	0.055 ± 0.017 mm.
tills overlying the Oldman formation	0.068 ± 0.022 mm.
tills overlying the Foremost formation	0.094 ± 0.03 mm.

The large dispersion about the mean is due to the fact that some till samples are located near the boundaries of bedrock formations.

If the difference between the above average graphic means is significant (that is, it could not have resulted from just random sampling), then it suggests that the texture of the tills is largely determined by the underlying bedrock.

In order to test whether the average graphic mean of tills on the Bearpaw formation is significantly different from the average graphic mean of tills on the Oldman formation, we set up the Null Hypothesis and assume the two average graphic means come from the same population (that is, we assume the bedrock does not determine the texture of the overlying till) and then attempt to disprove it.

The variance-Ratio test (Moroney, 1958, p. 234) shows that the sample variances are sufficiently alike to have come from the same population. The variance ratio F is 1.71 which is less than the value of F at the 5% level.

Student's t-test (Moroney, 1958, pp. 227-233) was used to test the significance of the difference between the average graphic means. Student's t is

calculated as:

$$t = \frac{\text{Difference of Means}}{\text{Standard Error of Difference}} = 2.29$$

The number of degrees of freedom for Student's t is 46. Referring the calculated value of t to tables of Student's t, with 46 degrees of freedom, we find that the chance of getting a value of t greater than 2.29 is 0.013, or 1.3%. This is significant and suggests that the average graphic mean of tills overlying the Bearpaw formation is significantly different from the average graphic mean of tills overlying the Oldman formation. In other words, the texture of the tills is largely controlled by the underlying bedrock.

A corollary of the above conclusion is that the tills are made up largely of local bedrock material. Figures 18 and 19 show that a change in texture of the local bedrock is almost immediately reflected in the overlying tills. The tills behind the Pakowki End Moraine (Figure 32) for the most part overlie the Foremost and Oldman formations. Consequently, they are coarser-grained than the older tills to the east and south which overlie argillaceous rocks of the Bearpaw and Pakowki formations.

Pebble composition

Two methods of collecting pebbles from till were used: for the purpose of this report one may be called "the field method" and the other "the bulk-till method". The field method involved the collection of about 200 pebbles from an outlined area of about 4 square feet. All pebbles between 2 and 70 millimetres in diameter were gathered, but clay pebbles were excluded because their colour was very similar to that of the till matrix, making it very difficult to get a representative value. The pebbles were identified and classified in the office (Table IV).

In order to check the supposition that a 200 - pebble sample collected in this way (field method) was representative of the true pebble composition of the

till, five adjacent samples were taken from the same till sheet at one locality and subjected to a chi-squared analysis. Chi-squared is given by the formula:

$$\chi^2 = \sum\left[\frac{(O-E)^2}{E}\right]$$

where O is the observed frequency and E is the expected frequency. Table II shows the frequency of erratic pebble types in the till samples, and $\chi^2 = 8.21$. The tables (Yule and Kendall, 1958, p. 665) show that at $P = 0.05$, with 8 degrees of freedom, $\chi^2 = 15.51$. As the obtained value of χ^2 is less than 15.51, we

Rock type \ Sample number	3062	3162	3262	3362	9761	TOTALS
Precambrian acidic rocks	74	57	60	61	68	320
Precambrian basic rocks	26	22	26	27	15	116
Palaeozoic carbonate rocks	79	91	86	96	89	441
TOTALS	179	170	172	184	172	877

TABLE II. Contingency table: Frequency variation of erratic pebbles in till samples taken from the same horizon at the same locality.

conclude that the variation in frequency of the three erratic pebble types in the samples is not significant. In other words, the variation in frequency does not exceed that which one would expect from random sampling. Hence, a 200-pebble sample obtained by the field method is representative of the erratic pebble composition of the till. When the frequencies of the pebbles of local origin are considered

(Table III), χ^2 increases to 33.57. The tables show that at P = 0.05, with 12 degrees of freedom, χ^2 = 21.03. The obtained value of χ^2 is greater than 21.03 and we conclude that the difference in frequency of pebbles of local origin is significant. This means that, unlike the erratic pebbles, the local pebbles are

Rock type \ Sample number	3062	3162	3262	3362	9761	TOTALS
Precambrian acidic rocks	74	57	60	61	68	320
Precambrian basic rocks	26	22	26	27	15	116
Palaeozoic carbonate rocks	79	91	86	96	89	441
Mesozoic and Cenozoic rocks of local derivation	12	19	29	11	40	111
TOTALS	191	189	201	195	212	988

TABLE III. Contingency table: Frequency variation of erratic and local pebbles in till samples taken from the same horizon at the same locality.

unevenly distributed throughout the till - variations in concentration being detectable at one locality.

The field method was used in 1961 and part of 1962 but was abandoned in favour of the more objective bulk-till method. In the latter method approximately 20 lb. of till was collected. All the material finer than 4 millimetres was removed by wet sieving in the laboratory and the composition of the 40 - 16 mm., 16 - 8 mm.,

and 8 - 4 mm. size fractions were recorded (Table V). In both the bulk-till and field methods, each pebble analysis was recast to include only erratic pebbles as only these are of importance in considerations of regional directions of ice movement. The change in sampling procedure, however, has hindered the recognition of significant changes in pebble lithology of the tills, for time did not permit bulk-till samples to be collected over the whole area.

The pebbles are classified into three main groups: Precambrian rocks from the Canadian Shield, Palaeozoic carbonate rocks from the rim of the Canadian Shield, and Mesozoic and Cenozoic rocks of local origin.

(1) Precambrian rocks from the Canadian Shield

Acidic rocks Igneous and metamorphic rocks of acidic composition are the most abundant rock types from the Canadian Shield. Granite, granophyre, pegmatite, syenite, quartz-feldspathic gneiss and metasediment, mica schist, and vein quartz are present.

Basic rocks All dark-coloured igneous and metamorphic rocks are grouped together. Amphibolite is the most common rock type in this class: diorite and gabbro with their fine-grained equivalents and greenstone also occur.

Athabasca sandstone White, grey, pink, red or purple orthoquartzite, medium to coarse-grained, and poorly to moderately cemented by silica is called Athabasca sandstone. This rock is exposed over a large area south and east of Lake Athabasca. Orthoquartzite is not abundant in the tills of the map-area and it is likely that some of it originally came from the Rocky Mountains.

(2) Palaeozoic carbonate rocks from the rim of the Canadian Shield

Buff, cream, sometimes pink, fine-grained dense dolomite and grey, fossiliferous limestone constitute the rock types of this category. They are always present in conspicuous amounts and rarely form less than 20 per cent of the pebbles in the till, and occasionally exceed 80 per cent.

(3) Mesozoic and Cenozoic rocks of local derivation

Quartzites Brown quartzite, black chert, arkose, quartzitic sandstone and conglomerate occur in this group. Most of the pebbles are well-rounded and all were derived from gravels that capped elevated remnants of Tertiary erosional surfaces or floored preglacial channels. Figure 22 shows the variation of quartzite pebble content in the tills with respect to the preglacial drainage channels.

Others All rocks in this class are derived from the Upper Cretaceous bedrock. They include soft, buff sandstone, clay ironstone, lignite, petrified wood, fragments of fossils, and semi-indurated shale.

The results of the pebble analyses are listed in Tables IV and V and plotted on a ternary diagram in Figure 20. The ratio of Palaeozoic carbonate to Precambrian crystalline pebbles was plotted on a map as a test of the variation of erratic pebble composition of the till sheets. Figure 21 suggests that tills of Pakowki age and younger contain less carbonate pebbles than the older tills to the east and south, with the exception of the till in the northeastern corner of the map-area (cf. Horberg, 1952, p. 317). However, the higher percentage of carbonate pebbles recorded around the Cypress Hills may in part be due to the sampling technique (field method) as is suggested in Figure 20.

Heavy minerals

The sand fraction between 120 - 230 mesh was obtained from 50 - 100 gm. till samples by wet sieving and the heavy minerals were separated in tetrabromoethane (sp. gr. = 2.96). A representative sample of the heavy minerals was obtained using the Jones' sample splitter. The grains were mounted in Aroclor (n = 1.66 to 1.67) and examined under the microscope. Over three hundred grains were counted from each slide.

A description of the heavy minerals is given below and the percentage frequency of each species in the till samples is shown in Table VI.

Opaques The opaque minerals are divided into three groups based on their colour in reflected light. Magnetite and ilmenite are black and form the first group; leucoxene is white and composes the second group. Hematite and limonite, which are reddish-brown and yellowish-brown respectively, constitute most of the opaques in the remaining group (designated "Others" in Table VI), but pyrite is conspicuous in some samples. In most of the till samples, opaques exceed 30 per cent of the heavy mineral suite. The local bedrock is undoubtedly the source of some opaque minerals in the till.

Tourmaline Two types of tourmaline occur. One variety is pleochroic in pink and dark-green, commonly peppered with inclusions, and is only slightly abraded; the other is pleochroic in olive and very dark green, is rounded and commonly contains secondary overgrowths. Most samples possess only trace amounts (less than one per cent), but in some, one per cent of the heavy mineral fraction is tourmaline.

Zircon The most common type of zircon is the colourless variety, usually a prism with pyramid terminations. Rounded, subrounded, fractured, and idiomorphic grains occur. The hyacinth variety is always well-rounded and sometimes shows zoning as does a brown, prismatic variety. Most of the zircon crystals contain

rod-shaped and globular inclusions. In tills that overlie the Oldman formation, zircon commonly makes up two per cent of the heavy mineral suite, but is present only in trace amounts in tills that sit on other bedrock formations (Table VI). This suggests a local source for at least some of the zircons (most likely the idiomorphic, volcanic zircons).

Garnet Most of the garnet is colourless to pale pink, clear and angular; the grains being bounded by conchoidal fracture surfaces. Dark brown and green garnets are present but rare. Inclusions of quartz, magnetite, and rutile are not uncommon. Garnet is an abundant heavy mineral in all the till samples (Table VI).

Epidote Epidote exhibits a distinct pleochroism from colourless to greenish-yellow. Subangular to subrounded equant grains predominate, but some elongate ones are present. Some grains are partially altered and cloudy, and a few possess inclusions. The occasional grain of clinozoisite is included with the epidote, which forms more than 5 per cent of the heavy minerals in most samples.

Rutile Deep reddish-brown to red rutile occurs in trace amounts.

Sphene Colourless, pale yellow, and brown sphene is present. The grains are equant and show variable degrees of roundness. Sphene occurs in small amounts on most of the slides and seldom exceeds 3 per cent of the heavy mineral suite.

Kyanite, Staurolite, Andalusite, and Sillimanite Only a few grains belonging to this metamorphic mineral assemblage were observed. Andalusite and staurolite are relatively more abundant than kyanite and sillimanite.

Hornblende The most common type of hornblende is pleochroic from green to bluish-green, and a variety pleochroic from green to brown is conspicuous. The majority of the hornblende grains are fresh-looking, prismatic cleavage fragments

that seldom show any degree of rounding. Inclusions are sometimes present. The occasional grain of actinolite was counted as hornblende, which is the second most abundant heavy mineral in the tills, commonly exceeding 30 per cent of the heavy mineral fraction.

Pyroxenes Pyroxenes are grouped into orthopyroxenes and clinopyroxenes (Table VI). Hypersthene, with its marked pleochroism from bluish-green to red or reddish-green, and enstatite occur in the former group. Augite predominates in the clinopyroxene group. Pyroxenes are scarce and seldom constitute more than 3 per cent of the heavy mineral suite.

Apatite Apatite occurs as rounded, fractured, and euhedral grains which are always clear and colourless and sometimes contain rod-shaped inclusions. Apatite forms 1 to 5 per cent of the heavy minerals and the idiomorphic forms are most likely derived from the local Cretaceous bedrock.

Biotite Brown, brownish-red, red, olive, and green biotite flakes are present, with some containing globular or rod-shaped inclusions surrounded by pleochroic haloes. A few hexagonal euhedral flakes were observed. The high percentage of biotite in the bedrock samples (Table VI), the flood of biotite in some till samples (2963, 3263, and 1863), and the presence of euhedral flakes, suggest that most of the biotite in the till was derived from the local Cretaceous bedrock, some of it being volcanic in origin.

Others Minerals that were too altered to be identified are included in this group, together with zoisite, monazite, dolomite, chlorite and chloritoid.

The ratio of hornblende to garnet in each till sample is given in Table VI, and Figure 23 shows the value of this ratio at each sample locality. Over most of the map-area, hornblende is more than twice as abundant as garnet, but variations in the

relative abundance of these two minerals show no noticeable trends.

Carbonate content

The percentage carbonate (calcite plus dolomite) in the matrix of each till sample was determined by means of the Chittick gasometric apparatus. The procedure is given by Dreimanis (1962). All the till samples were taken below the soil profile.

The results are given in Table VII and Figure 24, which show the carbonate content of the tills to be quite variable, ranging from 24 per cent to less than 1 per cent. Comparison of figures 21 and 24 shows that a positive correlation exists between the carbonate content of the till matrix and the carbonate pebble content of the till. Thus, a relatively large amount of carbonate is present in the matrix of tills immediately north of the Cypress Hills: the same tills contain relatively large amounts of dolomite and limestone pebbles. In the southeastern part of the map-area, the carbonate content of the till matrix is variable, high and low values being juxtaposed: the same situation exists with respect to the carbonate pebble content. This suggests that the carbonate in the till matrix is largely derived from the comminution of dolomite and limestone pebbles. The Oldman sandstone, however, has a dolomitic cement (Table VII), so some of the carbonate in the matrix of tills on this formation is of local origin.

The present results show considerable variation within one till sheet. The reason for this is not fully understood and the carbonate content of the till matrix must presently be regarded of little use as a parameter to differentiate till sheets in the map-area.

Petrography of Cypress Hills Loess

Heavy mineral studies verified the loessic origin of the sediment on the Cypress Hills Plateau. The heavy minerals present in the Cypress Hills loess and the

underlying Cypress Hills formation are shown in Table VIII. The Cypress Hills formation possesses a resistate suite of heavy minerals; opaques, tourmaline, zircon, epidote, sphene, and garnet are all present. Less stable minerals like hornblende are absent or occur as cloudy, dentate grains in trace amounts. The Cypress Hills loess, on the other hand, contains up to 17 per cent fresh blue-green hornblende as well as heavy minerals that are common to the Cypress Hills formation. This hornblende is identical to that found in nearby tills, and as the Laurentian glaciers did not overrun the Cypress Hills Plateau in the map-area, the hornblende could only have been transported to the plateau by the wind.

Cumulative curves of the Cypress Hills loess (Figure 25) show the sediment to be poorly sorted and in places coarse-grained; the median diameter of some loess samples is in the fine sand fraction. Both these characteristics may be explained, at least in part, by frost action churning up the loess (see Chapter V) and bringing up into it coarse material from the underlying Cypress Hills formation. However, much of the sand-sized material is loessic in origin (Figure 12) and points to strong winds in the region of the Cypress Hills during the period of loess deposition.

TABLE VIII HEAVY MINERAL COMPOSITION OF CYPRESS HILLS LOESS AND UNDERLYING CYPRESS HILLS FORMATION

Sample number	Size range mm.	Heavy minerals, per cent																								
		Opaques				Tourmaline	Zircon	Garnet	Epidote	Rutile	Sphene	Kyanite	Staurolite	Andalusite	Sillimanite	Hornblende	Orthopyroxenes	Clinopyroxenes	Apatite	Biotite		Others	
		Black	White	Others																			
Cypress Hills formation																							
2661	.177-.062	37	13	15		1	6	7	11	-	2	-	tr	tr	-	tr	-	-	*	-		8	
4461	.125-.062	27	22	12		2	tr	4	9	-	9	-	-	1	-	-	-	-	2	tr		9	
Cypress Hills loess																							
1061	.177-.062	19	8	21		1	tr	9	11	tr	3	-	-	-	-	17	-	-	-	tr		10	
1661	.177-.062	19	10	21		2	1	8	12	tr	4	tr	tr	-	-	14	-	tr	-	-		8	
1761	.177-.062	22	6	40		tr	1	3	8	tr	4	-	-	-	-	5	-	tr	-	-		9	
2561	.125-.088	22	9	17		tr	tr	5	10	-	6	-	-	3	-	8	-	tr	tr	tr		19	
2561	.088-.062	28	11	14		1	2	6	11	tr	6	-	tr	-	-	5	-	tr	2	tr		12	
2761	.177-.062	18	7	11		2	1	5	13	-	6	-	-	1	tr	15	-	tr	5	tr		15	

* Sample treated with HCl to remove iron staining - therefore no apatite.

Trace amounts less than 1 per cent

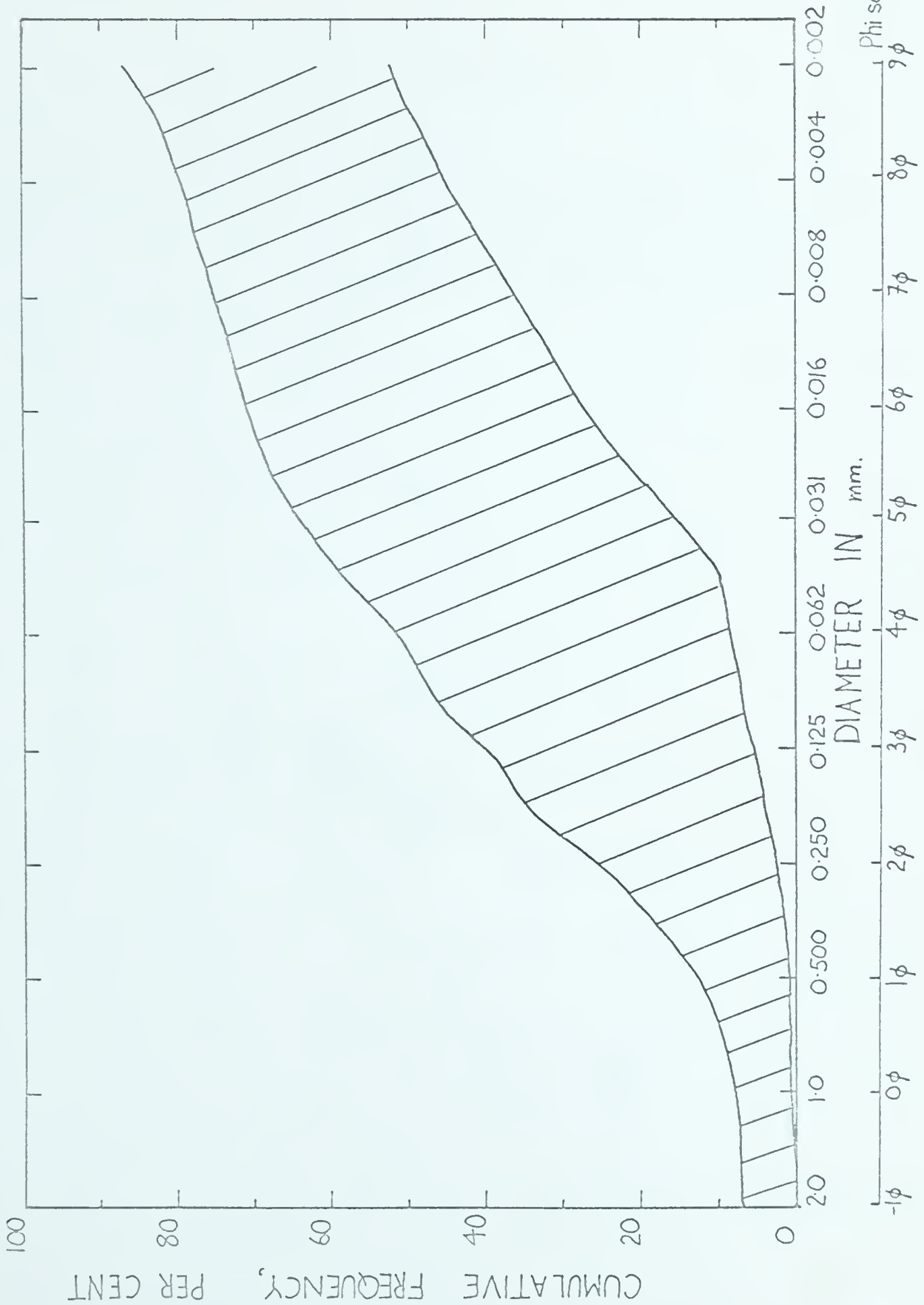


Figure 14. Range in grain size of till samples from the Foremost-Cypress Hills area

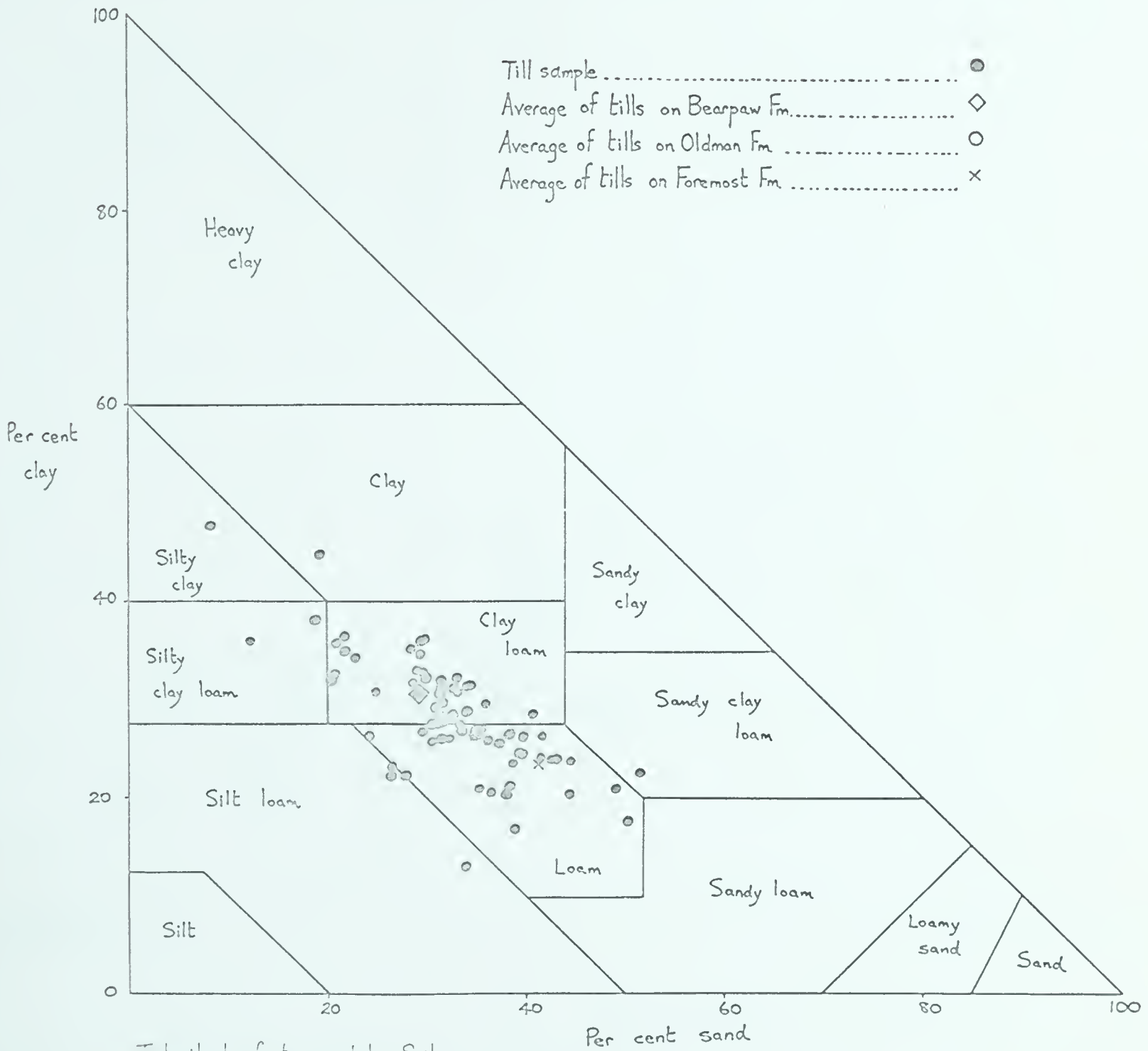
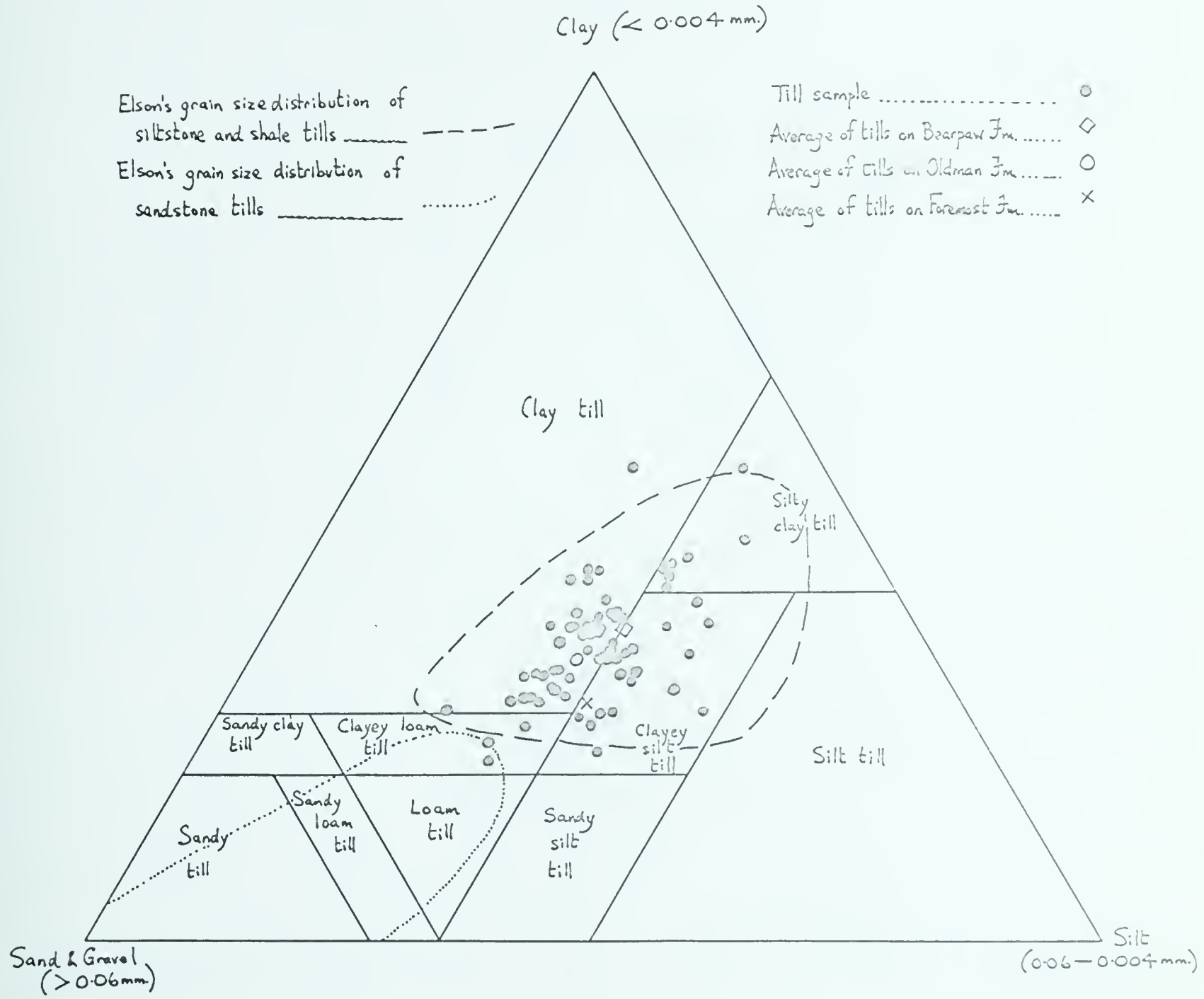


Figure 15. Textural classification of tills in the Foremost-Cypress Hills area



J.A. Elson's grain size classification, 1960

Figure 16. Textural classification of tills according to Elson, 1960

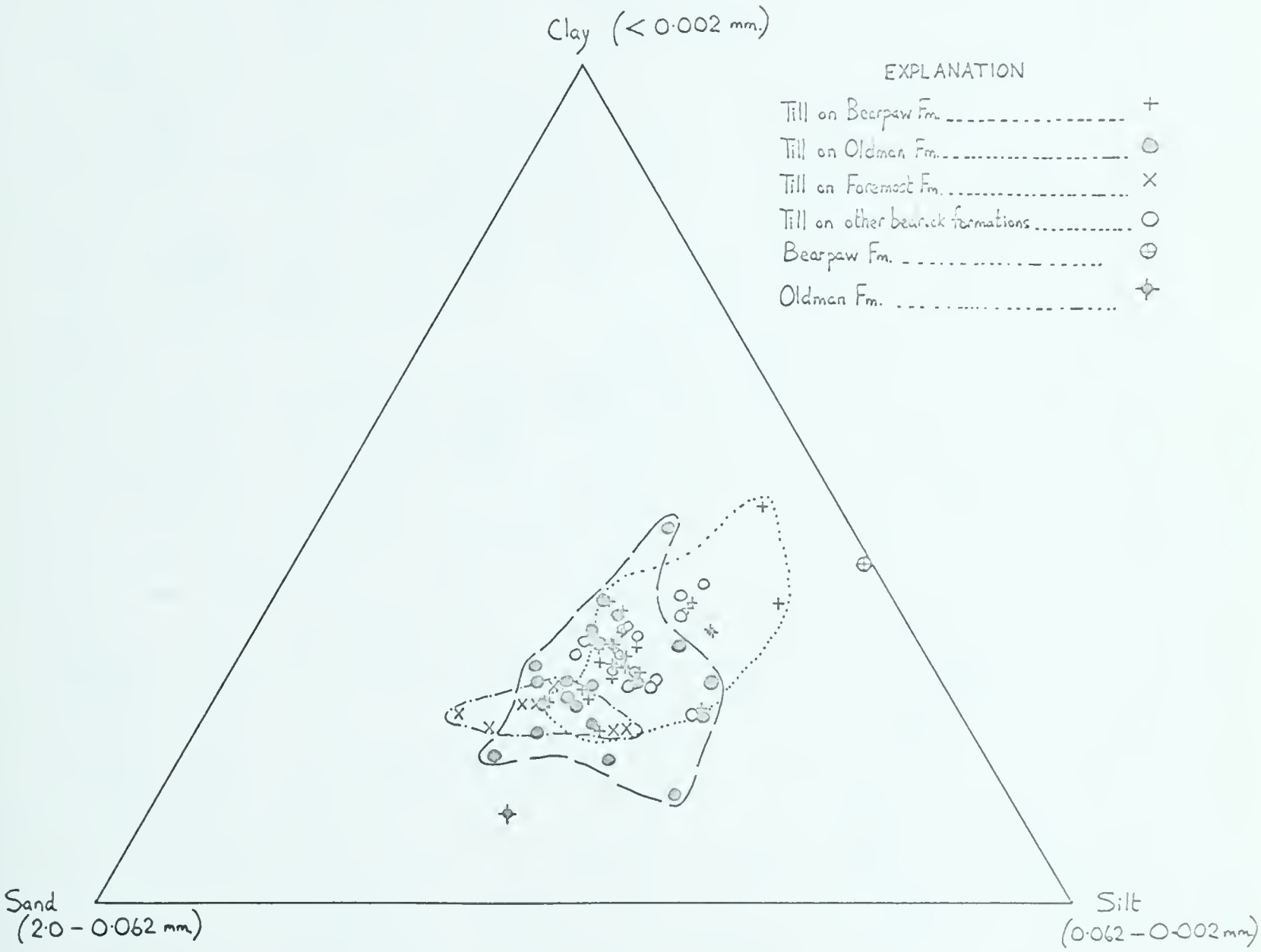


Figure 17. Texture of tills in the Foremost-Cypress Hills area- the underlying bedrock identified

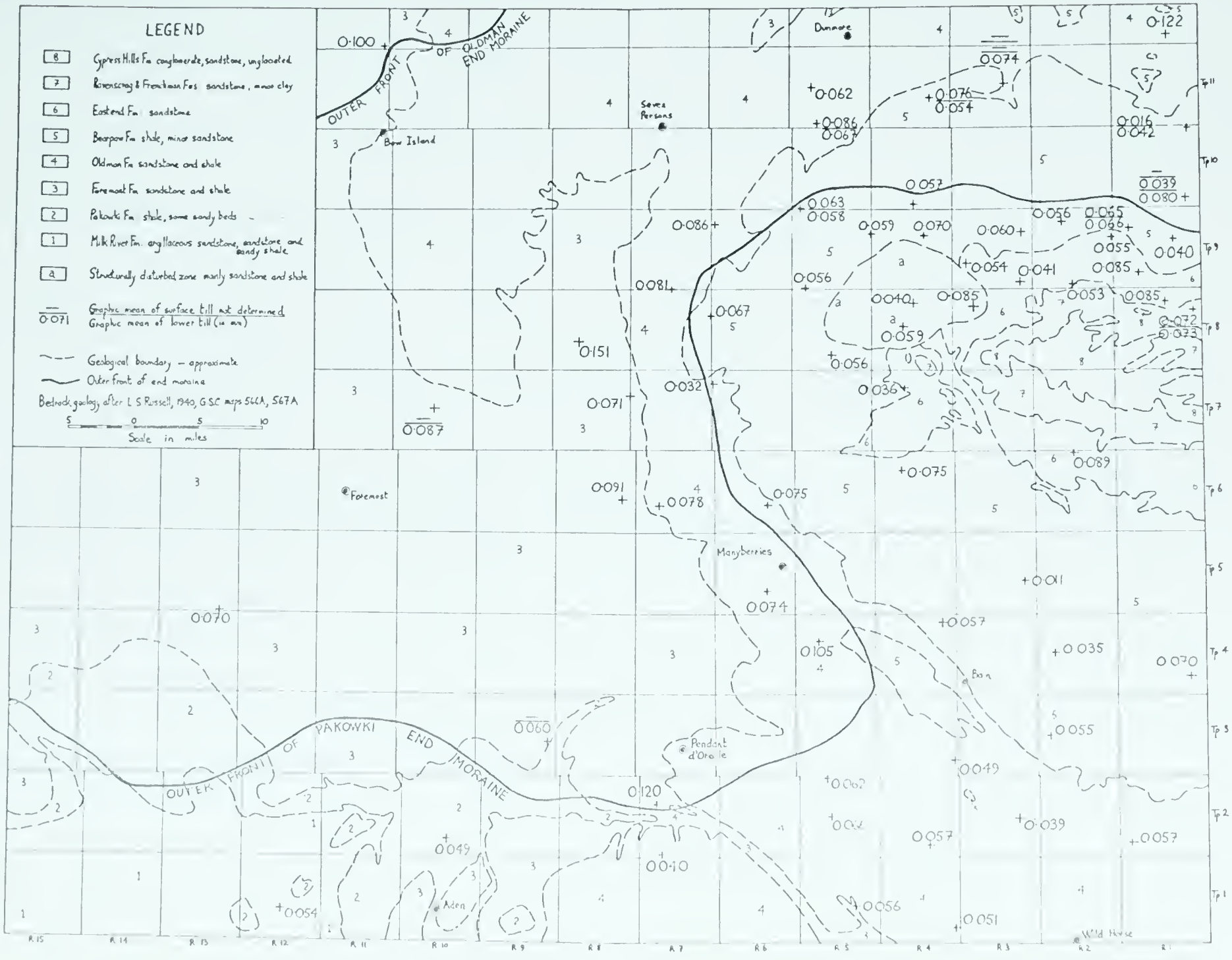


Figure 18. Textural variation of tills in the Foremost-Cypress Hills area with respect to the underlying bedrock

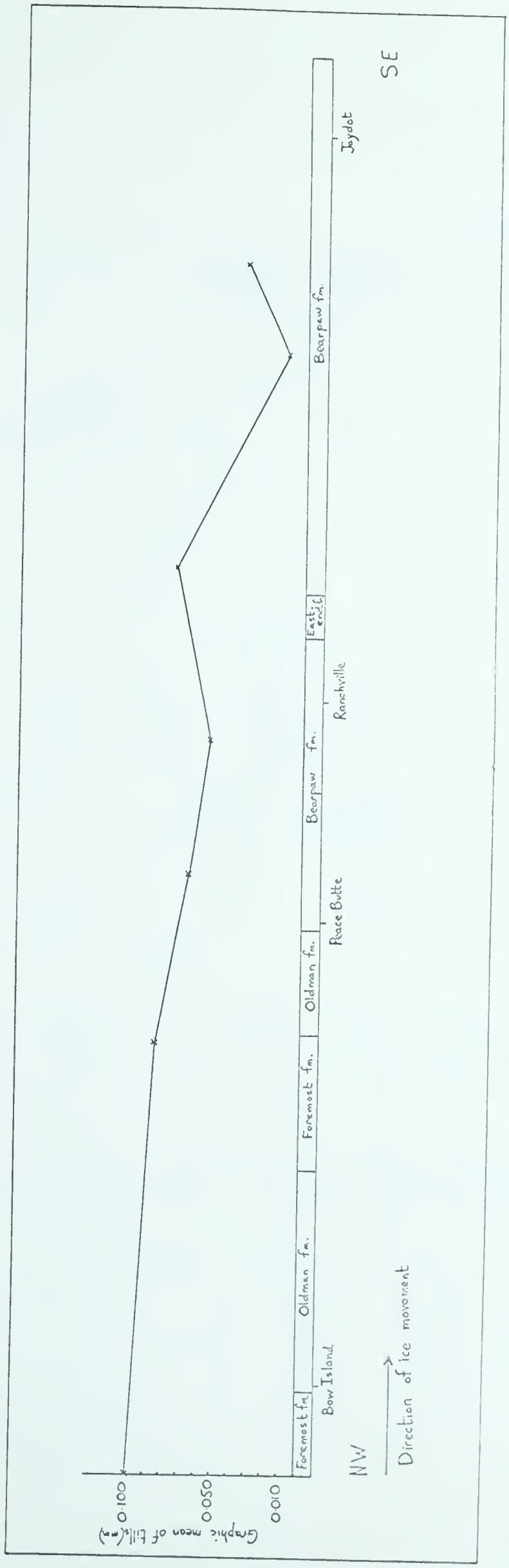


Figure 19. Variation in graphic mean of till with respect to the underlying bedrock

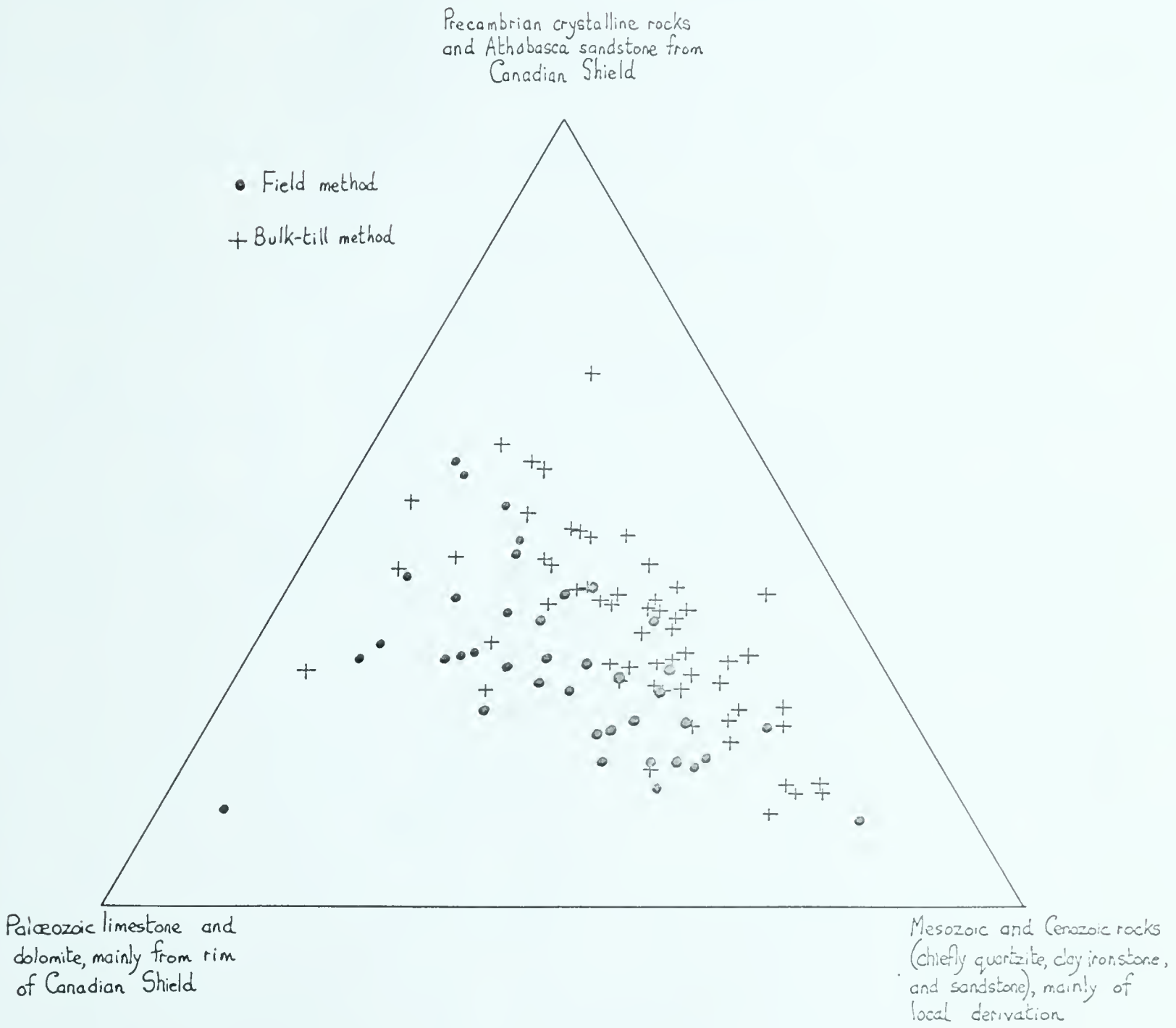


Figure 20. Pebble composition of tills in the Foremost-Cypress Hills area

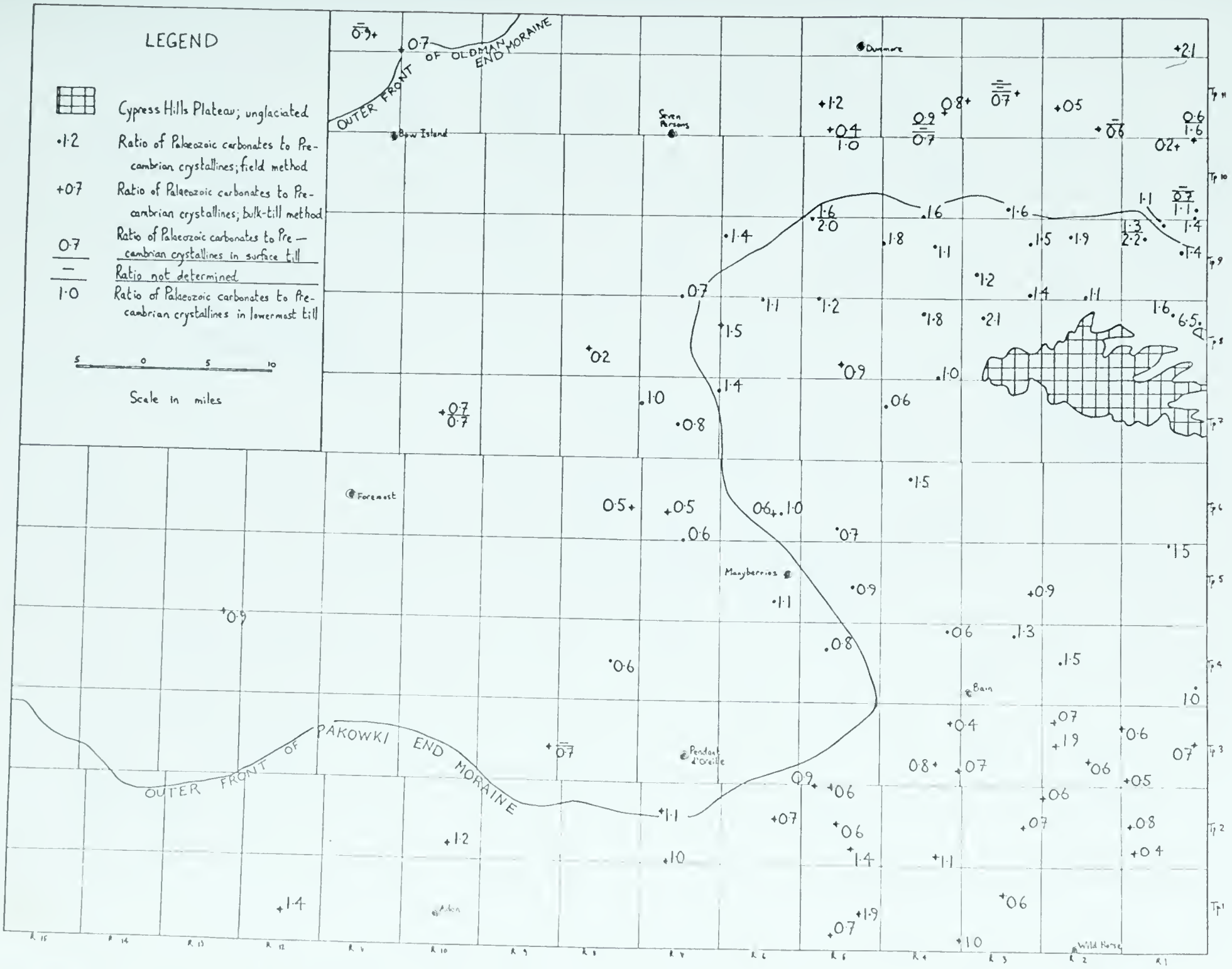


Figure 21. Ratio of Palaeozoic carbonate to Precambrian crystalline pebbles in tills of the Foremost-Cypress Hills area

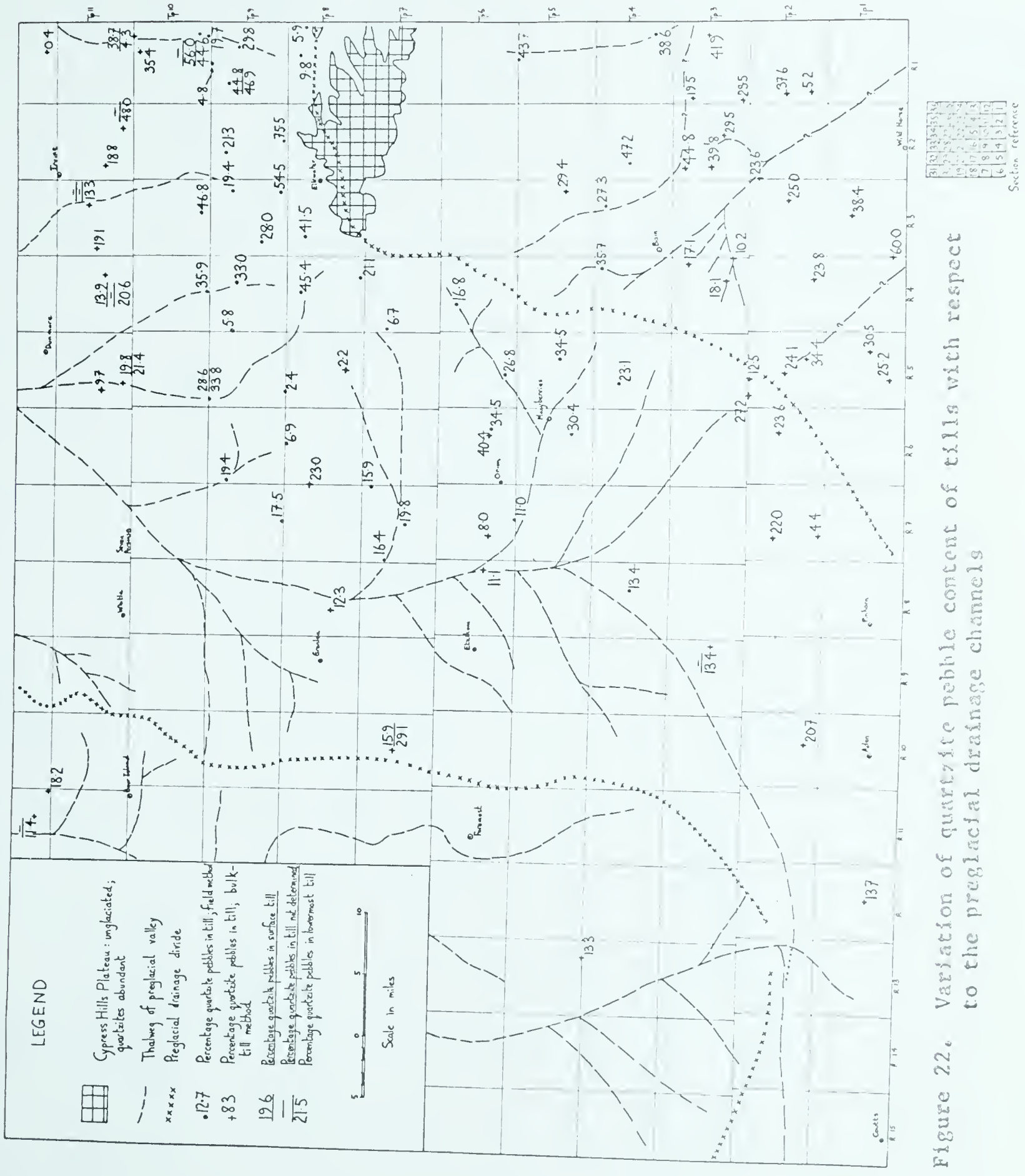


Figure 22. Variation of quartzite pebble content of tills with respect to the preglacial drainage channels

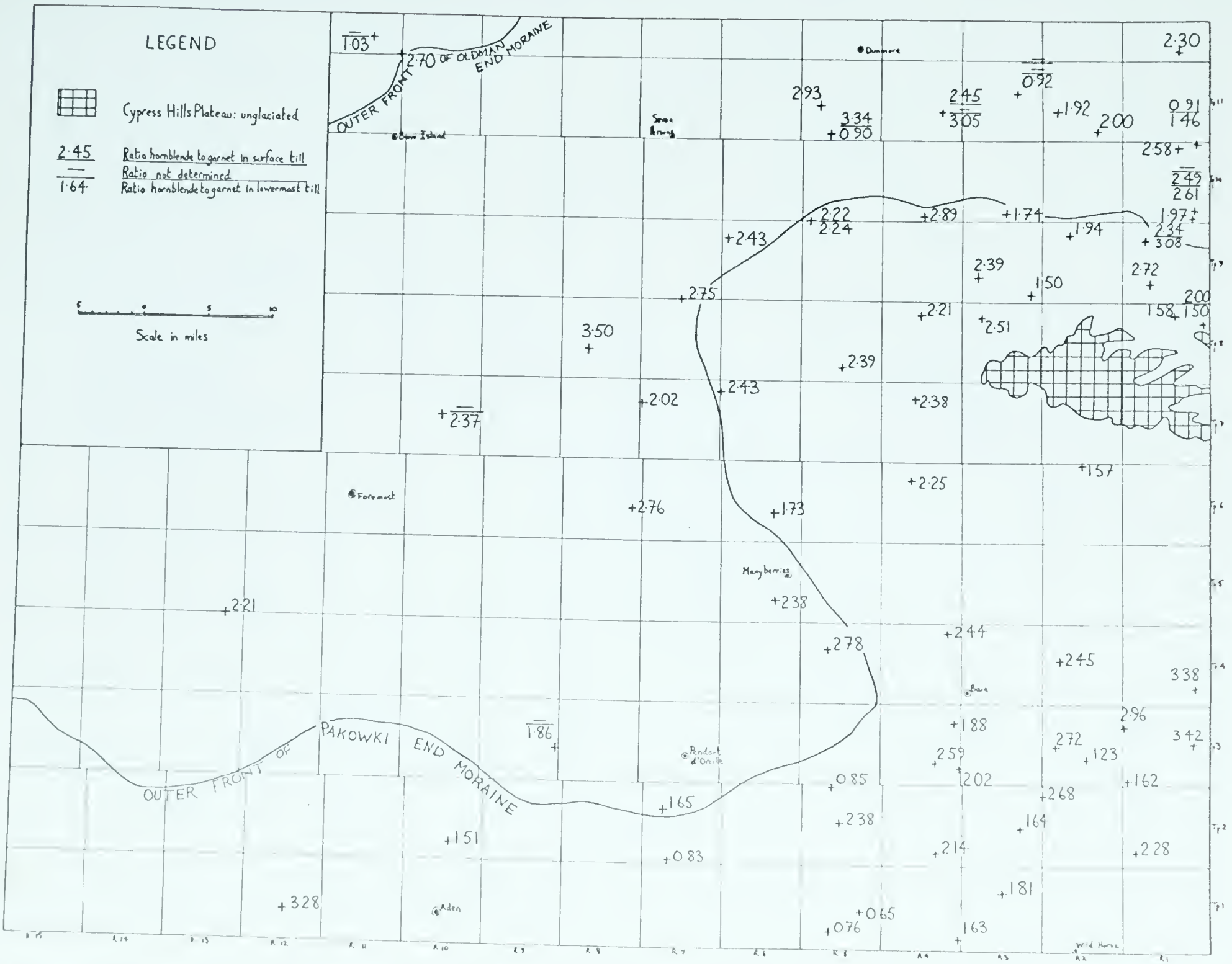


Figure 23. Ratio of hornblende to garnet in the tills of the Foremost-Cypress Hills area

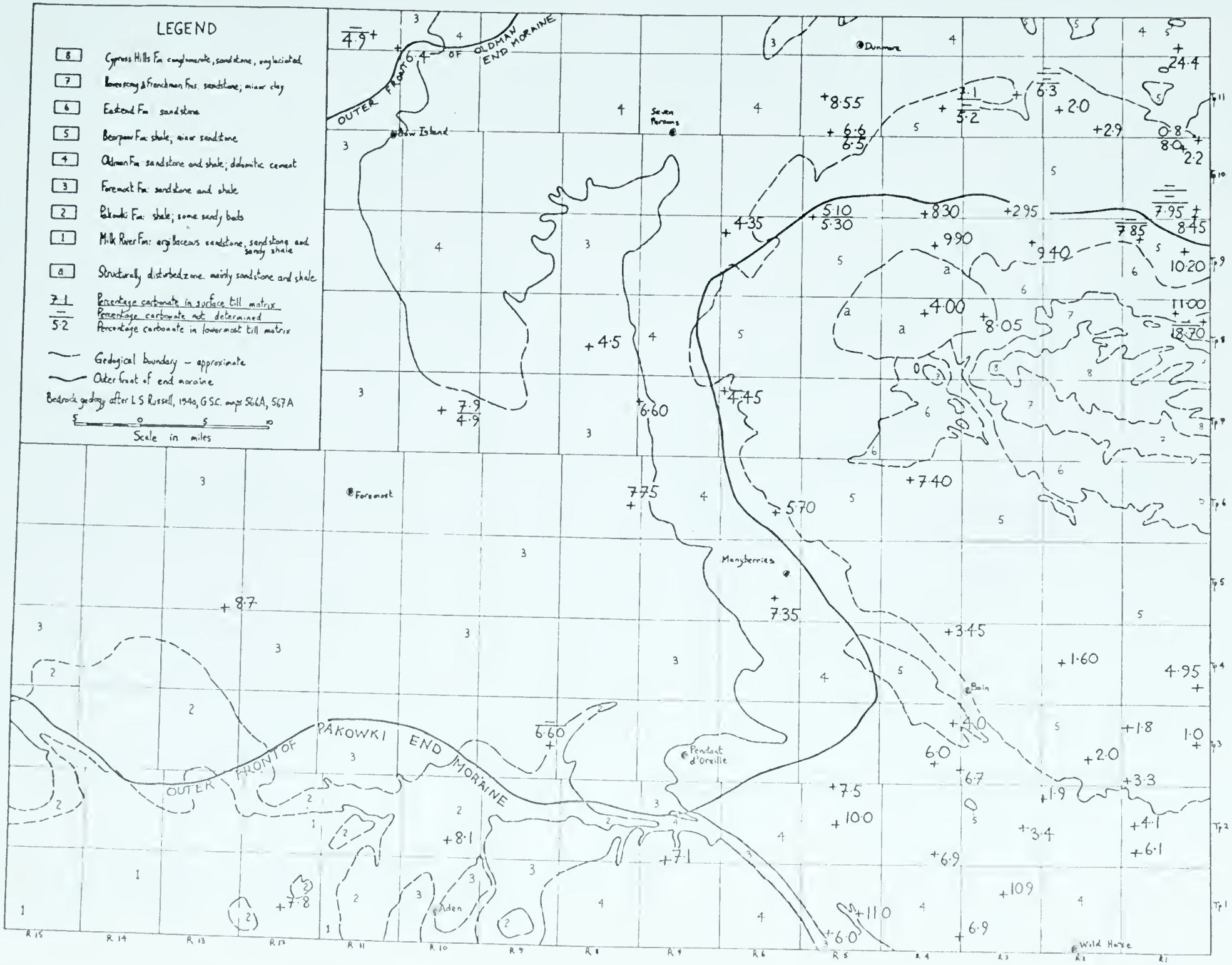


Figure 24. Percentage carbonate in tills of the Foremost-Cypress Hills area

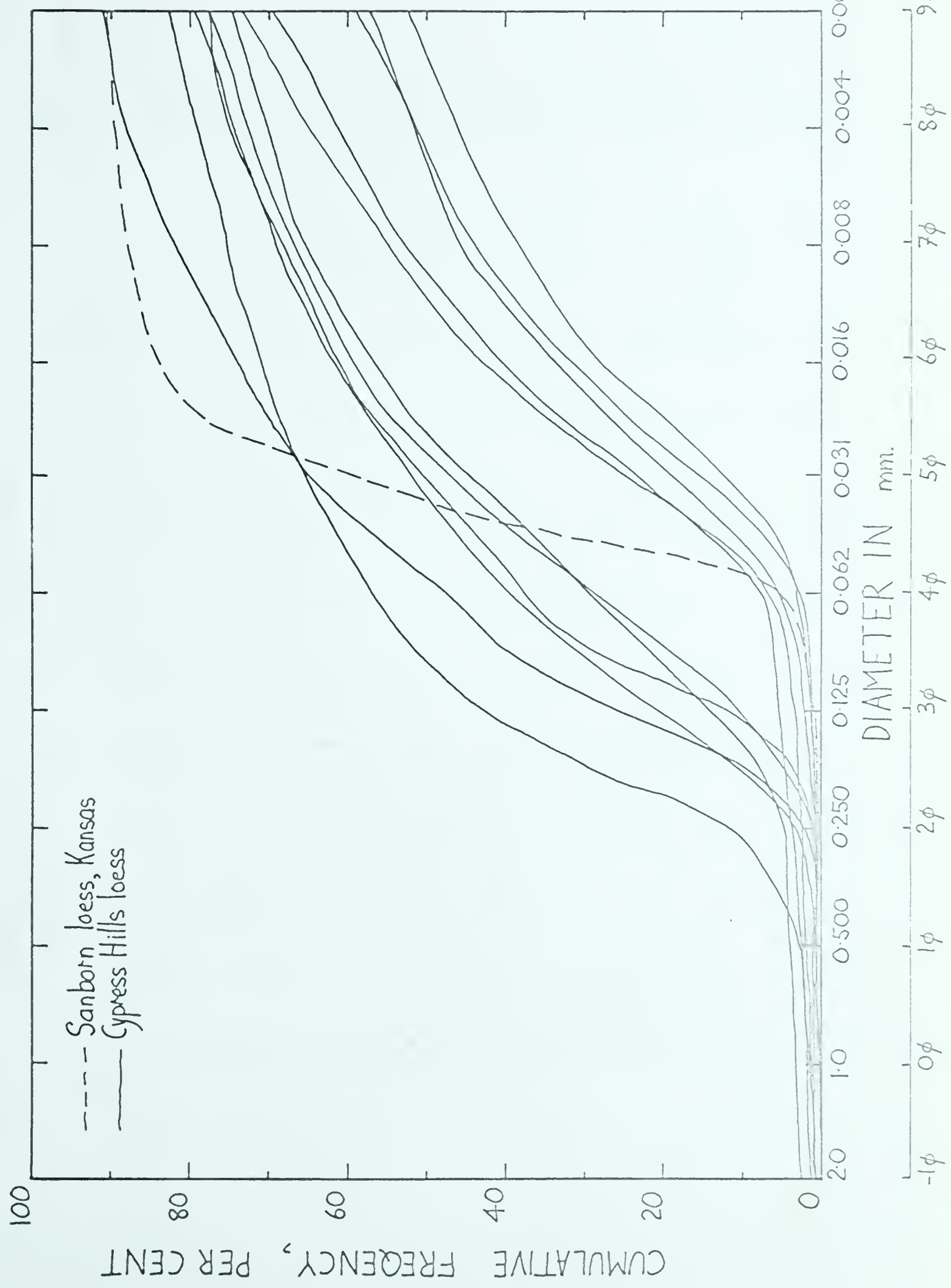


Figure 25. Cumulative curves of the Cypress Hills loess

TABLE I GRAIN-SIZE ANALYSES OF TILLS

Tills on Bearpaw Formation

Sample number	Size fractions in mm. Wt. per cent													Graphic mean (Folk) mm.	Stratigraphic horizon[1]
	4 to 2	2 to 1	1 to 0.5	0.5 to 0.25	0.25 to 0.125	0.125 to 0.105	0.105 to 0.074	0.074 to 0.062	0.062 to 0.0310	0.0310 to 0.0156	0.0156 to 0.0078	0.0078 to 0.0020	< 0.0020		
561	2.78	1.29	2.15	5.75	13.17	5.05	4.22	2.85	12.76	8.22	6.60	9.48	25.68	0.075	A
5361	1.16	0.94	1.50	3.43	6.46	2.63	2.36	1.98	14.27	12.98	9.11	10.97	32.21	0.040	A
6961	0.72	1.29	1.83	4.63	12.17	4.82	4.46	2.75	13.80	9.99	6.17	8.98	28.39	0.060	A
7361	1.80	1.10	1.89	4.45	10.42	4.37	4.18	2.66	13.13	9.36	6.98	10.27	29.39	0.057	A
7561	2.12	1.59	2.53	5.24	11.20	4.38	4.19	2.62	11.19	9.31	6.69	10.13	28.81	0.070	A
7961	1.20	1.15	2.96	7.25	13.96	5.31	4.81	2.86	12.09	8.81	5.75	9.32	24.53	0.080	C
8161	0.89	0.74	1.37	3.20	7.31	2.90	3.22	1.98	11.45	10.32	7.79	13.72	35.11	0.039	B
8561	1.03	0.80	1.66	3.62	12.39	5.18	4.76	3.02	14.32	9.39	6.62	9.03	28.18	0.055	A
8861	0.95	0.48	1.04	3.88	12.67	5.24	4.41	2.74	14.21	10.18	6.25	9.46	28.49	0.056	A
9361	2.13	1.55	2.47	5.18	10.26	3.88	3.77	2.42	11.53	9.14	6.38	9.76	31.53	0.066	B
9561	2.87	1.42	2.14	5.01	9.98	3.93	3.80	2.45	11.56	8.84	6.19	10.02	31.79	0.065	A
1862	1.34	0.81	1.04	3.17	6.49	2.67	2.88	2.10	13.60	11.10	8.50	13.60	32.70	0.035	A
2262	1.37	0.87	1.74	4.80	10.42	3.96	4.35	2.38	10.80	9.40	6.72	10.77	32.42	0.057	A
2862	0.59	1.51	2.20	5.53	13.27	5.90	5.70	3.30	17.40	13.30	2.40	8.30	20.60	0.070	A
5062	2.85	0.85	1.53	4.07	10.51	4.55	4.29	2.89	12.76	11.44	6.47	9.75	28.05	0.059	A
10062	2.27	1.14	2.45	4.87	9.50	3.99	3.76	2.30	13.61	10.33	6.69	11.36	27.73	0.063	A
10162	1.58	0.91	1.99	5.24	9.69	3.97	3.64	2.16	10.17	8.96	7.78	13.26	30.65	0.058	B
10262	1.03	1.76	2.56	5.68	8.60	3.84	3.59	2.24	8.96	6.68	5.95	13.12	35.99	0.056	A
10362	0.96	1.21	1.88	5.30	10.54	3.41	3.17	1.78	6.66	8.36	6.69	15.05	34.99	0.056	A

[1] A, uppermost till; B, middle till; C, lowermost till

TABLE I (cont.) GRAIN-SIZE ANALYSES OF TILLS

Tills on Bearpaw Formation

Sample number	Size fractions in mm. Wt. per cent													Graphic mean (Folk) mm.	Stratigraphic horizon[1]
	4 to 2	2 to 1	1 to 0.5	0.5 to 0.25	0.25 to 0.125	0.125 to 0.105	0.105 to 0.074	0.074 to 0.062	0.062 to 0.0310	0.0310 to 0.0156	0.0156 to 0.0078	0.0078 to 0.0020	<0.0020		
10562	0.44	0.57	1.68	7.19	13.05	4.56	4.00	2.05	10.03	6.83	6.33	16.47	26.80	0.067	A
11362	0.84	0.45	1.29	4.72	11.73	5.37	4.37	2.49	11.58	9.34	6.42	10.63	30.77	0.055	A
11462	0.41	0.38	0.49	1.36	2.77	0.95	1.08	0.79	7.58	11.47	10.11	15.07	47.54	0.011	A
11562	0.25	0.61	1.12	3.28	7.89	2.85	2.80	1.94	10.58	10.05	8.06	14.63	35.94	0.038	A
3563i	0.09	0.13	0.41	1.64	3.53	1.90	2.93	1.45	7.86	8.89	12.94	22.39	35.84	0.016	A
3563ii	1.01	0.19	0.38	1.23	6.39	4.84	7.75	4.27	23.12	13.69	6.42	7.53	23.18	0.042	B
3963i	0.54	0.73	1.61	4.53	10.03	5.45	7.34	2.79	11.93	11.05	3.10	10.29	30.61	0.054	B
3963ii	1.39	1.11	1.94	6.65	12.93	6.56	7.96	2.94	12.66	7.96	5.98	7.93	23.99	0.076	A

Tills on Oldman Formation

5362	6.73	0.91	1.58	5.06	11.47	5.26	4.74	2.66	11.88	3.43	10.24	9.50	26.54	0.086	A
5662	1.93	0.94	1.73	5.60	15.32	10.48	9.61	4.49	14.04	6.85	4.68	6.77	17.56	0.081	A
6762	1.58	0.74	2.04	7.29	13.71	5.48	5.03	3.02	13.28	11.72	7.68	11.57	16.86	0.074	A
7962	0.57	1.46	3.85	11.61	15.12	5.21	4.22	2.39	9.92	8.56	6.17	10.67	20.25	0.105	A
9962	1.99	1.19	1.61	4.60	10.64	4.44	4.17	2.73	14.47	12.58	7.27	8.06	26.25	0.062	A
10462	0.50	0.68	1.16	3.71	6.99	2.39	2.30	1.29	4.87	6.18	6.30	18.72	44.91	0.032	A
10662	1.69	1.25	2.33	6.89	13.37	6.25	5.76	3.07	10.17	7.79	5.48	7.65	28.30	0.078	A
10862	1.18	1.11	2.26	6.33	14.34	6.20	5.10	2.86	11.53	8.65	6.46	9.52	24.46	0.075	A
663	1.21	0.89	2.10	5.20	10.47	4.98	6.01	2.93	10.85	7.76	6.42	9.77	31.41	0.062	A
963	0.17	0.39	0.86	3.37	12.22	7.35	9.33	4.78	13.79	9.21	7.41	10.02	21.10	0.056	A

TABLE I (cont.) GRAIN-SIZE ANALYSES OF TILLS

Tills on Oldman Formation

Sample number	Size fractions in mm. Wt. per cent													Graphic mean (Folk) mm.	Stratigraphic horizon[1]
	4 to 2	2 to 1	1 to 0.5	0.5 to 0.25	0.25 to 0.125	0.125 to 0.105	0.105 to 0.074	0.074 to 0.062	0.062 to 0.0310	0.0310 to 0.0156	0.0156 to 0.0078	0.0078 to 0.0020	< 0.0020		
1063	1.39	0.66	1.94	6.58	10.23	4.45	5.27	1.89	8.76	7.41	7.04	11.75	32.23	0.066	A
1263	0.84	0.52	1.13	3.05	6.83	3.99	5.28	2.40	10.72	11.92	11.43	15.65	26.24	0.040	A
1463	0.85	0.58	1.67	4.26	9.21	4.59	5.60	2.34	10.70	8.79	6.87	10.09	34.45	0.049	A
1763	0.97	0.79	1.76	4.28	10.97	5.93	7.63	3.84	10.79	8.86	7.22	10.97	25.99	0.057	A
1863	1.19	0.75	0.86	2.72	11.78	6.10	4.80	4.50	10.60	8.30	6.70	10.60	31.10	0.051	A
2163	0.45	0.48	0.76	2.71	7.43	4.31	5.99	2.57	12.73	9.31	9.46	12.98	30.82	0.039	A
2463	1.27	0.95	2.22	5.08	9.09	4.15	4.97	2.04	9.09	7.53	6.21	11.28	36.12	0.057	A
3163	5.14	2.77	4.38	6.97	8.87	3.82	4.74	2.01	10.60	9.36	7.24	10.54	23.56	0.122	A
3763	1.32	0.92	2.11	6.93	13.64	6.40	7.50	2.70	11.00	7.28	5.51	8.45	26.24	0.074	C
4163i	2.04	1.24	1.87	5.30	10.94	6.07	7.80	2.96	11.93	7.88	6.07	9.43	26.47	0.067	B
4163ii	2.84	1.05	2.54	6.77	12.70	6.10	7.60	2.80	11.00	8.20	5.40	9.10	23.90	0.086	A

Tills on Foremost Formation

5862	1.66	0.78	1.76	6.07	13.39	5.32	4.66	2.73	12.35	9.59	8.54	12.45	20.70	0.071	A
10762	1.52	1.85	3.80	8.34	12.73	4.61	4.24	2.62	10.83	7.25	6.22	9.84	26.15	0.091	A
11062	3.62	1.99	3.83	9.18	14.57	7.45	5.80	2.67	11.10	7.71	5.56	5.62	20.90	0.120	A
4263	3.29	2.43	3.78	7.34	11.99	6.17	6.80	2.57	8.75	8.43	6.13	8.49	23.83	0.100	A
4563	2.35	2.78	6.13	14.26	14.33	4.52	4.83	2.18	6.95	5.63	5.30	8.14	22.60	0.151	A
4663ii	0.85	1.42	2.70	8.00	13.77	6.04	7.48	2.65	10.19	7.76	6.31	9.04	23.79	0.087	B
4763	0.90	1.02	2.40	6.39	10.14	5.01	6.57	2.64	13.41	10.21	8.52	11.85	20.94	0.070	A
4963	0.72	0.99	1.92	5.78	9.62	4.86	5.51	2.24	12.24	9.30	7.88	11.04	27.90	0.060	B

TABLE I (cont.) GRAIN-SIZE ANALYSES OF TILLS

Tills on Eastend Formation

Sample number	Size fractions in mm. Wt. per cent													Graphic mean (Folk) mm.	Stratigraphic horizon[1]
	4 to 2	2 to 1	1 to 0.5	0.5 to 0.25	0.25 to 0.125	0.125 to 0.105	0.105 to 0.074	0.074 to 0.062	0.062 to 0.0310	0.0310 to 0.0156	0.0156 to 0.0078	0.0078 to 0.0020	<0.0020		
861	2.18	1.05	2.19	3.20	5.30	1.90	1.95	0.97	12.67	10.24	7.45	12.84	38.06	0.036	A
1361	0.26	1.08	3.81	11.43	8.11	2.60	2.42	1.66	7.98	7.62	5.96	17.44	29.63	0.089	A
2361	1.64	1.20	1.98	4.58	9.04	3.89	3.51	2.51	12.22	9.48	6.96	11.18	31.81	0.054	A
3861	1.97	0.91	1.42	3.25	6.61	2.83	2.63	2.04	10.95	10.77	7.71	12.25	36.66	0.041	A
4661	0.60	1.07	1.76	4.39	10.40	4.31	3.78	2.66	11.80	8.84	7.14	10.23	33.02	0.053	A
6061	5.34	1.89	2.83	5.05	8.98	3.51	3.34	2.27	13.58	9.33	6.47	9.68	27.73	0.085	A
6461	2.26	1.92	3.41	6.74	11.40	4.04	3.82	2.43	11.09	7.94	5.16	10.09	29.70	0.085	A
9161	1.60	1.12	1.98	4.59	9.91	3.87	3.93	2.53	11.71	4.77	10.84	10.34	32.81	0.055	A

Tills on Frenchman formation

5761	2.13	1.71	3.08	5.90	9.46	3.72	3.70	2.47	13.28	10.22	7.36	10.90	26.07	0.072	A
5861	2.46	2.18	3.08	5.52	8.54	3.12	3.31	2.09	13.55	11.41	7.84	10.95	25.95	0.073	B

Till on Pakowki Formation

4863	0.79	0.72	1.61	4.52	8.10	4.07	3.64	4.22	11.19	11.61	11.38	15.87	22.28	0.049	A

Till on Milk River Formation

5163	1.71	0.87	1.63	4.65	8.65	4.09	5.58	2.23	12.20	8.97	8.33	14.70	26.39	0.054	A

BEDROCK SAMPLES

Bearpaw Formation					0.73	5.98	15.79	15.06	21.99	40.45	0.008	
Oldman Formation	0.08	5.12	12.62	19.78	14.63	24.04	6.35	3.07	3.66	10.65	0.061	

TABLE IV PEBBLE COMPOSITION OF TILLS (FIELD METHOD)

(The upper row refers to original analysis, the lower to recast analysis.
The recast analyses include only pebbles known to be foreign to the area)

Sample number	Sample depth, feet	Range in size mm.	Number of pebbles	Precambrian rocks from Canadian Shield, per cent			Palaeozoic carbonate rocks from rim of Canadian Shield, per cent	Mesozoic and Cenozoic rocks of local derivation, per cent		Palaeozoic Carbonates / Precambrian Crystallines	Stratigraphic horizon of till[1]
				Acidic rocks	Basic rocks	Athabasca sandstone	Limestone and dolomite	Quartzites	Others		
661	60	60-5	208 158	25.0 32.9	3.8 5.1	3.4 4.4	43.8 57.6	16.8 -	7.2 -	1.5	A
2461	4	60-2	207 140	26.6 39.3	3.4 5.0	1.5 2.1	36.2 53.6	28.0 -	4.4 -	1.2	A
2961	6	70-5	196 97	13.8 27.8	3.6 7.2	0.5 1.0	31.6 64.0	45.4 -	5.6 -	1.3	A
3561	6	70-5	207 114	14.5 26.3	3.4 6.1	0.5 0.9	36.7 66.6	41.5 -	3.4 -	2.1	A
3761	5	70-5	194 144	29.9 40.2	6.7 9.0	0.5 0.7	37.6 50.6	21.1 -	4.1 -	1.0	A
3961	5	60-5	202 89	17.3 39.4	1.5 3.4	- -	25.2 57.3	54.5 -	1.5 -	1.4	A
4761	5	90-5	204 47	10.3 44.7	0.5 2.1	- -	12.3 53.2	75.5 -	1.5 -	1.1	A
5561	10	70-5	198 132	22.7 34.1	5.6 8.3	- -	38.4 57.6	29.8 -	4.0 -	1.4	A
5961	6	60-5	202 188	9.9 10.6	2.5 2.7	- -	80.7 86.7	5.9 -	1.0 -	6.5	A

[1] A, uppermost till; B, middle till; C, lowermost till.

6161	10	70-5	205 177	28.3 32.8	4.9 5.7	- -	53.2 61.6	9.8 -	3.9 -	1.6	A
7061†	12	60-5	201 158	28.4 36.1	3.0 3.8	- -	47.3 60.1	19.4 -	1.5 -	1.5	A
7161†	12	70-5	196 139	21.9 30.9	2.6 3.6	- -	46.4 65.4	24.0 -	4.6 -	1.9	A
7461	20	60-5	217 124	16.6 29.0	5.1 8.9	- -	35.4 62.2	35.9 -	6.9 -	1.6	A
7661	20	60-5	200 126	25.5 40.5	5.5 8.7	- -	32.0 50.7	33.0 -	4.0 -	1.1	A
7761	12	70-5	192 90	12.5 26.7	5.7 12.2	- -	28.6 61.2	46.8 -	6.3 -	1.6	A
8061	25	50-5	204 98	16.2 33.7	6.9 14.3	- -	25.0 52.1	44.6 -	7.9 -	1.1	C
8261	25	80-5	209 81	18.7 48.2	3.3 8.7	0.5 1.2	16.5 42.0	56.0 -	4.8 -	0.7	B
8661	15	90-5	213 164	29.6 38.4	2.3 3.1	- -	45.1 58.6	19.7 -	3.3 -	1.4	A
8961	6	70-5	197 140	22.8 32.1	2.0 2.9	- -	46.2 65.0	21.3 -	7.6 -	1.9	A
9461	10	80-5	194 92	13.4 28.3	1.5 3.3	- -	32.4 68.5	46.9 -	5.7 -	2.2	B
9661	6	70-5	210 113	21.0 38.9	2.4 4.4	- -	30.4 56.6	44.8 -	1.4 -	1.3	A
9761	8	60-5	212 172	32.1 39.5	7.1 8.7	- -	42.0 51.7	16.5 -	2.4 -	1.1	A
1762	35	70-2	182 81	12.6 28.4	5.0 11.1	- -	26.9 60.5	47.2 -	8.2 -	1.5	A
2062	20	40-2	165 104	22.4 35.6	4.8 7.7	- -	35.8 56.7	27.3 -	9.7 -	1.3	A

† Replicate analyses

2162	8	70-2	168 98	22.6 38.8	13.7 23.5	- -	22.0 37.8	35.7 -	6.0 -	0.6	A
2762	3	50-2	190 106	16.3 29.2	5.8 10.4	- -	33.7 60.3	43.7 -	0.5 -	1.5	A
2962	12	70-2	197 116	22.3 37.9	6.6 11.2	0.5 0.9	29.4 50.0	38.6 -	2.5 -	1.0	A
3062†	8	60-2	195 183	37.9 40.4	13.3 14.2	2.1 2.2	40.5 43.1	3.6 -	2.6 -	0.8	A
3162†	8	70-2	189 170	30.1 33.5	11.6 12.9	- -	48.1 53.5	4.8 -	5.3 -	1.2	A
3262†	8	70-2	201 172	29.8 34.9	12.9 15.1	- -	42.8 50.0	10.4 -	4.0 -	1.0	A
3362†	8	70-2	196 185	31.1 33.0	13.8 14.6	0.5 0.5	49.0 51.8	3.6 -	2.2 -	1.1	A
4762	25	60-2	168 115	22.6 33.1	3.6 5.2	0.6 0.9	41.6 60.8	28.6 -	3.0 -	1.6	A
4862	60	80-5	186 110	14.0 23.6	5.4 9.1	0.5 0.9	39.2 66.4	33.8 -	7.0 -	2.0	B
4962	4	60-2	190 167	24.2 27.6	7.4 8.4	- -	56.3 64.1	5.8 -	6.3 -	1.8	A
5262	75	70-2	185 132	21.6 30.3	7.0 9.9	1.6 2.3	41.1 57.6	19.4 -	9.2 -	1.4	A
5562	3	80-2	200 156	32.0 41.0	10.5 13.5	4.0 5.1	31.5 40.4	17.5 -	4.5 -	0.7	A
5762	75	60-2	195 138	29.7 42.0	4.6 6.5	2.1 2.9	34.4 48.6	16.4 -	12.8 -	1.0	A
5962	85	80-5	192 149	31.8 40.9	10.4 13.4	2.6 3.4	32.8 42.3	19.8 -	2.6 -	0.8	A
6062	10	50-5	195 147	28.2 37.4	2.1 2.7	4.1 5.4	41.0 54.4	15.9 -	8.7 -	1.4	A

6162	15	40-2	202 178	37.1 42.1	4.9 5.6	- -	46.0 52.2	6.9 -	5.0 -	1.1	A
6362	15	40-2	212 203	38.7 40.4	4.2 4.4	1.9 2.0	51.0 53.2	2.4 -	1.9 -	1.2	A
6462	3	70-2	195 175	46.7 52.0	8.7 9.7	1.0 1.1	33.3 37.1	6.7 -	3.6 -	0.6	A
6662	10	70-2	204 108	21.6 40.7	2.9 5.6	2.5 4.6	26.0 49.1	30.4 -	16.7 -	1.1	A
7162	3	60-2	209 184	44.5 50.5	9.6 10.9	0.5 0.5	33.4 38.0	11.0 -	1.0 -	0.6	A
7562	2	70-2	201 164	42.8 52.4	7.0 8.5	1.0 1.2	30.8 37.8	13.4 -	5.0 -	0.6	A
7662	50	70-2	190 128	33.7 50.0	6.3 9.4	0.5 0.8	26.8 39.8	26.8 -	5.8 -	0.7	A
7762	20	50-2	197 99	21.3 42.4	3.0 6.1	1.5 3.0	24.4 48.5	34.5 -	15.2 -	1.0	A
7862	20	60-2	203 109	21.7 40.4	5.9 11.0	2.5 4.6	23.6 44.1	34.5 -	11.8 -	0.9	A
8062	3	70-2	216 151	33.3 47.7	5.1 7.3	1.4 2.0	30.1 43.1	23.1 -	7.0 -	0.8	A

TABLE V PEBBLE COMPOSITION OF TILLS (BULK-TILL METHOD)

(Recast analyses include only pebbles known to be foreign to the area.)

Sample number	Sample depth, feet	Grade mm.	No. of pebbles	Precambrian rocks from Canadian Shield, per cent			Palaeozoic carbonate rocks from rim of Canadian Shield, per cent	Mesozoic and Cenozoic rocks of local derivation, per cent		Palaeozoic Carbonates / Precambrian Crystallines	Stratigraphic horizon of Till[1]
				Acidic rocks	Basic rocks	Athabasca sandstone	Limestone and dolomite	Quartzites	Others		
9962	15	16-40	3	33.3	-	-	33.3	33.3	-		A
		8-16	18	44.4	-	-	44.4	5.6	5.6		
		4- 8	93	22.6	8.6	-	40.9	9.7	18.3		
		Total	114	26.3	7.0	-	41.2	9.7	15.8		
		Recast	85	35.3	9.4	-	55.3	-	-	1.2	
10062	25	16-40	2	-	-	-	-	100.0	-		A
		8-16	32	34.4	3.1	-	28.1	34.4	-		
		4- 8	188	46.3	2.7	1.1	25.0	12.2	12.8		
		Total	222	44.2	2.7	0.9	25.2	16.2	10.8		
		Recast	162	60.5	3.7	1.2	34.6	-	-	0.5	
10162	55	16-40	4	25.0	-	-	-	75.0	-		B
		8-16	28	42.9	-	-	14.3	28.6	14.3		
		4- 8	190	34.7	1.6	1.1	23.1	15.8	23.7		
		Total	222	35.6	1.4	0.9	21.6	18.5	22.0		
		Recast	132	59.8	2.3	1.5	36.4	-	-	0.6	
10262	15	16-40	-	-	-	-	-	-	-		A
		8-16	17	47.0	11.8	-	35.3	-	5.9		
		4- 8	112	40.2	-	-	48.2	7.2	4.5		
		Total	129	41.1	1.6	-	46.5	6.2	4.6		
		Recast	115	46.1	1.7	-	52.2	-	-	1.1	

[1] A, uppermost till; B, middle till; C, lowermost till.

10362*	5	16-40	1	100.0	-	-	-	-	-		A
		8-16	11	18.2	-	18.2	45.4	9.1	9.1		
		4- 8	79	44.3	6.3	2.5	40.5	1.3	5.1		
		Total	91	41.7	5.5	4.4	40.7	2.2	5.5		
		Recast	84	45.3	5.9	4.8	44.1	-	-	0.9	
10462	10	16-40	3	-	-	-	-	100.0	-		A
		8-16	28	28.6	-	-	28.6	39.3	3.6		
		4- 8	166	38.6	1.2	2.4	24.1	19.9	13.8		
		Total	197	36.5	1.1	2.0	24.4	23.8	12.2		
		Recast	126	57.2	1.6	3.2	38.1	-	-	0.6	
10562*	4	16-40	-	-	-	-	-	-	-		A
		8-16	6	-	-	-	33.3	66.7	-		
		4- 8	55	20.0	1.8	-	29.1	18.2	30.9		
		Total	61	18.0	1.6	-	29.6	23.0	27.8		
		Recast	30	36.7	3.3	-	60.0	-	-	1.5	
10662	6	16-40	2	50.0	-	-	50.0	-	-		A
		8-16	22	45.5	-	4.5	22.7	18.2	9.1		
		4- 8	127	54.3	3.2	-	25.2	6.3	11.0		
		Total	151	53.0	2.6	0.6	25.2	8.0	10.6		
		Recast	123	65.1	3.2	0.8	30.9	-	-	0.5	
10762	12	16-40	4	25.0	-	-	75.0	-	-		A
		8-16	64	45.4	1.6	1.6	34.4	14.0	3.1		
		4- 8	383	55.4	3.1	2.9	25.9	10.7	2.1		
		Total	451	53.0	2.8	2.7	27.5	11.1	2.9		
		Recast	388	61.7	3.4	3.1	32.0	-	-	0.5	
10862	10	16-40	3	33.3	-	-	-	33.3	33.3		A
		8-16	16	18.7	-	-	18.7	62.5	-		
		4- 8	100	31.0	-	2.0	17.0	37.0	13.0		
		Total	119	29.4	-	1.7	16.8	40.4	11.7		
		Recast	57	61.4	-	3.5	35.1	-	-	0.6	

* Number of pebbles in sample is small and probably not representative of true pebble composition of till.

11062	4	16-40	4	-	-	-	25.0	75.0	-		A
		8-16	147	19.0	0.7	3.4	27.2	44.2	5.4		
		4- 8	732	21.9	1.0	-	24.4	17.2	35.7		
		Total	883	21.3	0.9	0.6	24.8	22.0	30.4		
		Recast	420	44.8	1.9	1.2	52.2	-	-	1.1	
11362*	3	16-40	3	-	-	-	-	100.0	-		A
		8-16	15	-	-	-	20.0	53.3	26.6		
		4- 8	60	15.0	-	-	23.3	33.3	28.4		
		Total	78	11.5	-	-	21.8	39.8	26.9		
		Recast	26	34.6	-	-	65.4	-	-	1.9	
11462*	3	16-40	1	-	-	-	-	100.0	-		A
		8-16	8	25.0	-	-	12.5	37.5	25.0		
		4- 8	42	26.2	2.4	-	26.2	26.2	19.0		
		Total	51	25.5	2.0	-	23.5	29.4	19.6		
		Recast	26	50.0	3.8	-	46.2	-	-	0.9	
11562	15	16-40	5	-	-	-	20.0	80.0	-		A
		8-16	31	16.1	6.5	-	19.3	54.8	3.2		
		4- 8	149	28.2	5.4	-	32.2	26.2	8.1		
		Total	185	25.4	5.4	-	29.7	32.4	7.1		
		Recast	112	41.9	8.9	-	49.1	-	-	1.0	
663	12	16-40	2	-	-	-	50.0	50.0	-		A
		8-16	14	35.7	21.4	7.1	21.4	7.1	7.1		
		4- 8	104	39.4	7.7	1.9	29.8	12.5	8.7		
		Total	120	38.3	9.2	2.5	29.1	12.5	8.3		
		Recast	95	48.4	11.6	3.2	36.9	-	-	0.6	
763*	4	16-40	-	-	-	-	-	-	-		A
		8-16	13	23.1	-	15.4	15.4	38.4	7.7		
		4- 8	59	28.8	-	8.5	22.0	20.4	20.4		
		Total	72	27.8	-	9.7	20.9	23.6	18.1		
		Recast	42	47.7	-	16.6	35.7	-	-	0.7	

863i	10	16-40	8	25.0	-	-	25.0	37.5	12.5		A
		8-16	17	11.8	5.9	-	35.3	41.2	5.9		
		4- 8	130	39.2	2.3	-	24.6	22.3	11.5		
		Total	155	35.5	2.6	-	25.8	25.2	11.0		
		Recast	99	55.6	4.0	-	40.4	-	-	0.7	
863ii	12	16-40	3	-	33.3	-	-	66.7	-		A
		8-16	13	-	-	7.7	38.5	15.4	38.5		
		4- 8	128	35.9	3.9	0.8	24.2	17.2	18.0		
		Total	144	31.9	4.2	1.4	25.0	18.1	19.4		
		Recast	90	51.2	6.7	2.2	40.0	-	-	0.7	
963*	8	16-40	-	-	-	-	-	-	-		A
		8-16	12	25.0	-	-	16.7	50.0	8.3		
		4- 8	70	14.3	1.4	-	34.3	27.2	22.9		
		Total	82	15.9	1.2	-	31.8	30.5	20.7		
		Recast	40	32.5	2.5	-	65.0	-	-	1.9	
1063	4	16-40	3	33.3	-	-	-	66.7	-		A
		8-16	22	9.1	9.1	-	18.2	50.0	13.6		
		4- 8	187	31.5	-	11.8	17.6	20.3	18.7		
		Total	212	29.2	0.9	10.4	17.5	24.1	17.9		
		Recast	123	50.4	1.6	17.9	30.1	-	-	0.6	
1163	10	16-40	7	28.6	-	-	14.3	42.9	14.3		A
		8-16	21	28.6	-	-	47.6	9.5	14.3		
		4- 8	141	28.4	2.1	-	25.5	29.1	14.9		
		Total	169	28.4	1.8	-	27.8	27.2	14.8		
		Recast	98	49.0	3.1	-	48.0	-	-	0.9	
1263	10	16-40	-	-	-	-	-	-	-		A
		8-16	17	11.8	-	-	41.2	11.8	35.3		
		4- 8	142	21.8	4.9	2.8	23.2	3.5	43.6		
		Total	159	20.7	4.4	2.5	25.2	4.4	42.7		
		Recast	84	39.3	8.3	4.8	47.7	-	-	1.0	

1363	30	16-40	3	33.3	-	-	33.3	33.3	-	0.8	A
		8-16	10	10.0	10.0	-	40.0	20.0	20.0		
		4- 8	114	28.1	1.8	1.8	22.8	17.5	28.1		
		Total	127	26.8	2.4	1.6	24.4	18.1	26.8		
		Recast	70	48.6	4.3	2.9	44.3	-	-		
1463	50	16-40	1	-	-	-	-	100.0	-	0.7	A
		8-16	14	14.3	7.1	-	28.6	7.1	42.9		
		4- 8	122	33.6	9.0	-	28.7	9.8	18.8		
		Total	137	31.4	8.8	-	28.4	10.2	21.2		
		Recast	94	45.8	12.8	-	41.5	-	-		
1563*	15	16-40	-	-	-	-	-	-	-	0.4	A
		8-16	10	40.0	10.0	10.0	20.0	10.0	10.0		
		4- 8	66	42.4	3.0	-	19.7	18.2	16.7		
		Total	76	42.1	3.9	1.3	19.8	17.1	15.8		
		Recast	51	62.7	5.9	2.0	29.4	-	-		
1763	5	16-40	2	-	-	-	-	100.0	-	1.1	A
		8-16	25	16.0	4.0	-	20.0	32.0	28.0		
		4- 8	149	20.1	0.7	0.7	22.1	21.5	34.9		
		Total	176	19.3	1.1	0.6	21.6	23.8	33.5		
		Recast	75	45.4	2.7	1.3	50.7	-	-		
1863	16	16-40	12	-	-	-	8.3	91.7	-	1.0	A
		8-16	51	7.9	-	-	3.9	82.4	5.9		
		4- 8	154	17.5	-	-	18.8	50.0	13.6		
		Total	217	14.3	-	-	14.7	60.0	11.0		
		Recast	63	49.2	-	-	50.8	-	-		
1963	4	16-40	-	-	-	-	-	-	-	0.6	A
		8-16	30	13.3	3.3	6.7	13.3	56.7	6.7		
		4- 8	168	33.3	1.8	3.6	20.8	35.1	5.4		
		Total	198	30.3	2.2	4.0	19.7	38.4	5.6		
		Recast	111	54.1	3.6	7.2	35.1	-	-		

2163*	8	16-40	3	-	-	-	33.3	-	66.7			A
		8-16	11	18.2	9.1	-	18.2	45.5	9.1			
		4- 8	70	31.4	-	-	21.5	22.9	24.3			
		Total	84	28.6	1.2	-	21.4	25.0	23.8			
		Recast	43	55.8	2.3	-	41.9	-	-	0.7		
2263*	3	16-40	-	-	-	-	-	-	-			A
		8-16	8	12.5	-	-	12.5	75.0	-			
		4- 8	68	23.6	2.9	-	19.1	41.2	13.2			
		Total	76	22.4	2.6	-	18.4	44.8	11.8			
		Recast	33	51.6	6.1	-	42.4	-	-	0.7		
2363*	15	16-40	4	50.0	-	-	-	25.0	25.0			A
		8-16	24	16.7	4.2	-	4.2	41.7	33.3			
		4- 8	78	23.1	2.6	9.0	18.0	18.0	29.5			
		Total	106	22.7	2.8	6.6	14.1	23.6	30.2			
		Recast	49	49.0	6.1	14.3	30.6	-	-	0.6		
2463	12	16-40	3	33.3	-	-	33.3	33.3	-			A
		8-16	16	25.0	-	-	31.2	6.3	37.4			
		4- 8	116	53.4	6.0	0.9	23.3	4.3	12.1			
		Total	135	49.6	5.2	0.7	24.4	5.2	14.8			
		Recast	108	62.1	6.5	0.9	30.6	-	-	0.4		
2563	14	16-40	4	-	25.0	-	-	75.0	-			A
		8-16	37	13.5	-	-	21.6	59.5	5.4			
		4- 8	185	24.3	1.1	0.5	20.0	32.4	21.6			
		Total	226	22.1	1.3	0.4	19.9	37.6	18.6			
		Recast	99	50.6	3.0	1.0	45.5	-	-	0.8		
2663*	10	16-40	-	-	-	-	-	-	-			A
		8-16	13	53.8	-	-	7.7	30.8	7.7			
		4- 8	75	28.0	4.0	-	22.7	29.4	16.0			
		Total	88	31.8	3.4	-	20.4	29.5	14.8			
		Recast	49	57.2	6.1	-	36.8	-	-	0.6		

		16-40	1	-	-	-	-	-	100.0		
		8-16	10	30.0	10.0	-	10.0	40.0	10.0		
2763*	10	4- 8	66	30.3	1.5	-	22.8	16.7	28.8		A
		Total	77	29.9	2.6	-	20.8	19.5	27.3		
		Recast	41	56.2	4.9	-	39.1	-	-	0.6	
		16-40	2	50.0	-	-	50.0	-	-		
		8-16	15	40.0	-	-	20.0	33.3	6.7		
2863*	35	4- 8	85	44.7	3.5	-	23.6	22.4	5.9		A
		Total	102	44.1	2.9	-	23.5	23.5	5.9		
		Recast	72	62.6	4.2	-	33.4	-	-	0.5	
		16-40	2	-	-	-	50.0	50.0	-		
		8-16	12	-	8.3	-	25.0	58.3	8.3		
2963*	20	4- 8	60	26.7	3.3	3.3	16.7	38.4	11.7		A
		Total	74	21.6	4.1	2.7	18.9	41.9	10.8		
		Recast	35	45.7	8.6	5.7	40.0	-	-	0.7	
		16-40	10	10.0	-	10.0	-	80.0	-		
		8-16	61	9.8	1.6	3.3	24.6	49.2	11.5		
3063	5	4- 8	322	12.4	0.6	0.6	16.8	30.1	39.4		A
		Total	393	12.0	0.8	1.3	17.6	34.4	34.1		
		Recast	124	37.9	2.4	4.0	55.6	-	-	1.4	
		16-40	6	-	-	-	100.0	-	-		
		8-16	74	25.7	2.7	-	66.3	-	5.4		
3163	15	4- 8	660	27.2	3.3	-	62.3	0.5	6.8		A
		Total	740	26.8	3.2	-	63.0	0.4	6.6		
		Recast	688	28.8	3.5	-	67.7	-	-	2.1	
		16-40	1	100.0	-	-	-	-	-		
		8-16	9	66.7	11.1	-	-	-	22.2		
3263*	45	4- 8	91	30.8	2.2	-	19.8	20.9	26.4		A
		Total	101	34.6	3.0	-	17.8	18.8	25.8		
		Recast	56	62.5	5.4	-	32.2	-	-	0.5	

3363	40	16-40	3	-	-	-	-	66.7	33.3		B
		8-16	27	7.4	3.7	-	14.8	70.4	3.7		
		4- 8	122	22.9	2.5	0.8	14.7	42.6	16.4		
		Total	152	19.7	2.6	0.7	14.5	48.0	14.5		
		Recast	57	52.7	7.0	1.8	38.6	-	-	0.6	
3463*	25	16-40	-	-	-	-	-	-	-		A
		8-16	9	22.2	-	-	-	66.7	11.1		
		4- 8	39	43.6	-	-	10.3	28.2	17.9		
		Total	48	39.6	-	-	8.3	35.4	16.7		
		Recast	23	82.7	-	-	17.4	-	-	0.2	
3563*i	10	16-40	-	-	-	-	-	-	-		A
		8-16	5	-	-	-	20.0	80.0	-		
		4- 8	39	23.1	2.6	2.6	12.8	33.4	25.6		
		Total	44	20.4	2.3	2.3	13.6	38.7	22.7		
		Recast	17	53.0	5.9	5.9	35.3	-	-	0.6	
3563*ii	85	16-40	-	-	-	-	-	-	-		B
		8-16	3	33.3	33.3	-	33.3	-	-		
		4- 8	44	22.7	2.3	-	45.5	4.6	25.0		
		Total	47	23.4	4.3	-	44.7	4.3	23.4		
		Recast	34	32.4	5.9	-	61.7	-	-	1.6	
3763	60	16-40	2	50.0	-	-	-	50.0	-		C
		8-16	18	38.8	-	-	11.1	27.8	22.2		
		4- 8	191	31.4	6.3	1.0	28.3	11.5	21.5		
		Total	211	32.2	5.7	0.9	26.6	13.3	21.3		
		Recast	138	49.3	8.7	1.5	40.6	-	-	0.7	
3863	8	16-40	3	-	-	33.3	33.3	33.3	-		A
		8-16	48	18.8	6.3	14.6	29.2	27.1	4.2		
		4- 8	263	29.6	1.9	17.9	23.6	17.5	9.5		
		Total	314	27.7	2.5	17.5	24.5	19.1	8.6		
		Recast	227	38.3	3.5	24.2	33.9	-	-	0.8	

3963i	30	16-40	1	-	-	-	-	100.0	-		C
		8-16	14	21.4	-	-	21.4	21.4	35.7		
		4- 8	121	33.9	2.5	-	24.8	19.8	19.0		
		Total	136	32.4	2.2	-	24.3	20.6	20.6		
		Recast	80	55.0	3.8	-	41.3	-	-	0.7	
3963ii	10	16-40	5	-	-	-	40.0	60.0	-		A
		8-16	38	15.8	10.5	2.6	34.2	18.4	18.4		
		4- 8	231	34.2	5.2	1.3	32.0	12.1	15.2		
		Total	274	31.0	5.8	1.5	32.5	13.9	15.3		
		Recast	194	43.8	8.3	2.1	45.9	-	-	0.9	
4063	40	16-40	-	-	-	-	-	-	-		A
		8-16	18	44.4	11.1	-	38.9	-	5.6		
		4- 8	163	37.4	4.3	-	28.8	11.0	18.4		
		Total	181	38.1	5.0	-	29.8	10.0	17.1		
		Recast	132	52.3	6.8	-	40.9	-	-	0.7	
4163i	100	16-40	2	-	-	-	-	100.0	-		B
		8-16	29	17.3	-	3.5	34.5	31.0	13.8		
		4- 8	161	28.6	-	0.6	24.8	18.6	27.3		
		Total	192	26.6	-	1.4	26.0	21.4	25.0		
		Recast	103	49.5	-	1.9	48.6	-	-	1.0	
4163ii	15	16-40	6	16.7	-	-	16.7	33.3	33.3		A
		8-16	33	33.3	6.1	-	12.1	36.4	12.1		
		4- 8	223	40.8	3.6	0.4	20.2	17.0	17.9		
		Total	262	39.3	3.8	0.4	19.1	19.8	17.5		
		Recast	164	62.7	6.1	0.6	30.5	-	-	0.4	
4263	20	16-40	3	33.3	-	-	33.3	33.3	-		A
		8-16	38	34.2	5.3	-	21.0	21.0	18.4		
		4- 8	190	34.2	3.7	2.6	29.0	17.4	13.2		
		Total	231	34.2	3.9	2.2	27.7	18.2	13.8		
		Recast	157	50.3	5.7	3.2	40.8	-	-	0.7	

4363	30	16-40	2	-	-	-	-	100.0	-			
		8-16	13	15.4	7.7	-	46.2	15.4	15.4			
		4- 8	134	44.0	3.0	-	39.6	9.7	3.7			B
		Total	149	40.9	3.4	-	39.6	11.4	4.7			
		Recast	125	48.8	4.0	-	47.2	-	-	0.9		
4563	10	16-40	4	25.0	-	-	-	75.0	-			
		3-16	48	31.3	10.4	12.5	20.8	20.8	4.2			
		4- 8	346	55.3	3.8	11.3	12.1	10.4	7.2			A
		Total	398	52.0	4.5	11.3	13.1	12.3	6.8			
		Recast	322	64.3	5.6	14.0	16.1	-	-	0.2		
4663i	15	16-40	3	33.3	-	-	-	66.7	-			
		8-16	32	34.4	3.1	-	34.4	18.7	9.4			
		4- 8	179	43.0	0.6	1.7	29.6	14.5	10.6			A
		Total	214	41.6	0.9	1.4	29.9	15.9	10.3			
		Recast	158	56.3	1.3	1.9	40.5	-	-	0.7		
4663ii	20	16-40	5	-	-	-	20.0	40.0	40.0			
		8-16	27	22.2	-	-	11.1	51.8	14.8			
		4- 8	222	25.2	3.6	3.6	20.7	26.1	20.7			B
		Total	254	24.4	3.1	3.1	19.7	29.1	20.5			
		Recast	128	48.4	6.2	6.2	39.1	-	-	0.7		
4763	15	16-40	7	28.6	-	-	28.6	42.9	-			
		8-16	22	18.2	4.5	4.5	22.7	27.3	22.7			
		4- 8	227	25.6	1.3	4.8	22.5	11.0	34.8			A
		Total	256	25.0	1.6	4.7	22.6	13.3	32.8			
		Recast	138	46.4	2.9	8.7	42.0	-	-	0.9		
4863	15	16-40	3	-	-	-	-	100.0	-			
		8-16	37	8.1	-	2.7	27.0	37.9	24.3			
		4- 8	211	12.8	-	3.8	12.3	16.6	54.4			A
		Total	251	12.0	-	3.6	14.3	20.7	49.4			
		Recast	75	40.0	-	12.0	48.0	-	-	1.2		

4963	60	16-40	2	-	-	-	50.0	50.0	-		
		8-16	29	27.6	-	13.8	31.0	17.2	10.3		
		4- 8	178	30.4	1.7	6.7	18.5	12.4	30.4		B
		Total	209	29.7	1.4	7.7	20.6	13.4	27.3		
		Recast	124	50.0	2.4	12.9	34.7	-	-	0.7	
5163	10	16-40	4	-	-	-	-	-	100.0		
		8-16	38	7.9	-	-	15.8	18.4	57.8		
		4- 8	192	14.1	0.5	2.6	18.8	13.0	51.0		A
		Total	234	12.8	0.4	2.1	17.9	13.7	53.0		
		Recast	78	38.5	1.3	6.4	53.8	-	-	1.4	

TABLE VI HEAVY MINERAL COMPOSITION OF TILLS

Tills on Bearpaw Formation

Sample number	Heavy minerals, per cent (0.125 - 0.062 mm. fraction)																					Ratio hornblende to garnet
	Opaques				Tourmaline	Zircon	Garnet	Epidote	Rutile	Sphene	Kyanite	Staurolite	Andalusite	Sillimanite	Hornblende	Orthopyroxenes	Clinopyroxenes	Apatite	Biotite		Others		
	Black	White	Others																			
561	14	5	21		tr	tr	10	5	tr	3	-	tr	-	-	23	tr	-	2	4		11		2.25
2861	9	3	15		tr	tr	15	5	tr	-	-	-	-	tr	33	tr	-	2	7		10		2.20
7361	9	3	19		tr	tr	11	7	-	2	-	-	tr	-	33	-	tr	3	2		11		2.89
7961	12	3	12		1	tr	14	6	-	tr	-	-	-	-	37	2	tr	2	3		8		2.61
8161	12	3	15		1	tr	14	5	tr	2	-	-	-	-	33	1	tr	2	5		8		2.49
8561	12	5	22		tr	tr	11	7	tr	1	-	-	tr	-	22	tr	-	4	5		12		1.97
8861	14	6	23		2	tr	11	7	tr	2	-	-	tr	-	21	1	-	3	2		9		1.94
9361	10	2	15		-	tr	12	5	tr	1	-	-	-	-	37	2	-	2	3		11		3.08
9561	16	3	11		-	tr	14	6	tr	2	-	-	-	-	33	tr	-	2	1		11		2.34
1862	3	3	40		tr	tr	9	4	tr	1	-	-	-	-	21	tr	-	1	2		13		2.45
2262	11	4	22		1	-	11	6	tr	1	-	-	tr	-	27	-	1	3	5		9		2.44
2862	8	4	15		-	tr	10	6	-	tr	-	tr	tr	tr	34	1	tr	3	5		13		3.38
10062	11	3	15		-	1	13	7	-	3	-	-	-	-	28	1	tr	3	6		11		2.22
10162	10	5	25		-	1	11	4	tr	1	-	-	-	-	26	1	-	1	2		13		2.24
10362	11	5	9		tr	tr	15	7	-	2	-	-	-	-	36	2	1	2	-		10		2.39
11362	11	9	26		tr	tr	8	5	-	2	-	-	tr	-	21	tr	-	2	4		11		2.72

Trace amounts less than 1 per cent

TABLE VI (cont.)

Tills on Bearpaw Formation (cont.)

Sample number	Heavy minerals, per cent (0.125 - 0.062 mm. fraction)																					Ratio hornblende to garnet
	Opaques																					
	Black	White	Others		Tourmaline	Zircon	Garnet	Epidote	Rutile	Sphene	Kyanite	Staurolite	Andalusite	Sillimanite	Hornblende	Orthopyroxenes	Clinopyroxenes	Apatite	Biotite		Others		
11562	9	4	18		-	-	12	6	-	4	-	-	2	tr	22	tr	tr	2	5		16		1.74
1563	15	3	13		tr	tr	15	6	-	2	-	-	tr	-	28	tr	-	2	6		10		1.88
2663	16	4	11		-	tr	17	6	-	1	-	tr	tr	tr	21	tr	-	1	5		16		1.23
2763	12	7	22		-	1	8	4	tr	1	-	-	-	-	23	tr	-	2	6		13		2.96
2863	18	3	9		-	tr	15	4	tr	2	-	-	-	-	25	tr	-	2	3		17		1.62
2963	19	2	8		tr	tr	9	3	tr	tr	-	tr	-	-	30	-	-	1	19		8		3.42
3263	11	7	14		tr	tr	12	4	-	tr	-	-	-	-	23	tr	-	2	13		12		1.92
3363	13	5	16		tr	tr	13	6	tr	1	-	-	-	-	27	1	tr	tr	5		12		2.00
3463	12	4	19		-	tr	11	6	tr	tr	tr	-	-	tr	27	tr	-	2	5		11		2.58
3563i	24	2	16		-	2	16	4	tr	tr	-	-	-	-	15	tr	-	tr	tr		19		0.91
3563ii	19	1	20		tr	1	17	6	-	tr	-	-	-	-	25	tr	-	1	1		9		1.46
3963i	13	4	17		-	1	10	7	tr	tr	-	-	-	-	31	-	-	tr	6		9		3.05
3963ii	11	7	19		tr	1	11	8	tr	2	-	-	-	-	27	1	-	tr	2		10		2.45
Tills on Oldman Formation																						
5362	13	5	9		tr	-	13	7	tr	1	-	-	tr	-	31	-	tr	5	5		10		2.43
5662	14	5	15		-	1	11	7	tr	2	tr	-	tr	-	29	1	tr	tr	1		13		2.75

TABLE VI (cont.)

Tills on Oldman Formation (cont.)

Sample number	Heavy minerals, per cent (0.125 - 0.062 mm. fraction)																					Ratio hornblende to garnet
	Opaques																					
	Black	White	Others		Tourmaline	Zircon	Garnet	Epidote	Rutile	Sphene	Kyanite	Staurolite	Andalusite	Sillimanite	Hornblende	Orthopyroxenes	Clinopyroxenes	Apatite	Biotite		Others		
6762	15	7	22		tr	2	8	5	-	tr	tr	-	2	-	19	tr	-	2	3		14		2.38
7962	14	4	19		-	tr	9	8	tr	2	-	-	-	-	25	3	-	2	3		12		2.78
9962	15	2	20		tr	2	9	6	tr	2	-	-	-	-	26	2	tr	2	4		10		2.93
10462	14	3	16		-	tr	12	7	tr	tr	-	-	tr	-	28	tr	1	4	3		10		2.43
10862	16	2	16		tr	1	11	7	-	2	-	tr	-	-	20	tr	-	1	5		18		1.73
663	20	3	11		-	1	21	6	-	1	-	-	-	-	18	2	tr	1	2		15		0.85
863ii	21	2	9		-	1	25	3	-	tr	-	tr	tr	-	19	1	tr	2	1		14		0.76
963	25	5	12		-	2	14	5	1	tr	-	tr	-	-	9	-	-	2	5		19		0.65
1063	16	5	15		-	1	12	8	-	tr	tr	tr	-	-	28	tr	tr	2	-		10		2.38
1263	20	5	20		tr	2	13	5	tr	2	-	-	-	-	11	-	-	1	2		20		0.83
1363	11	tr	20		tr	2	11	5	tr	2	-	-	-	-	29	2	-	2	4		10		2.59
1463	14	4	18		tr	tr	15	4	tr	tr	-	-	tr	-	29	tr	-	2	3		9		2.02
1763	20	8	12		tr	1	9	9	-	tr	-	-	tr	-	19	tr	tr	5	3		13		2.14
1863	15	3	16		tr	2	6	4	tr	2	-	-	-	-	10	tr	-	2	21		17		1.63
1963	29	3	14		1	tr	9	7	tr	2	-	-	-	-	15	-	-	2	tr		17		1.81
2163	15	7	16		tr	1	11	6	-	tr	-	tr	-	-	17	tr	tr	1	6		18		1.64
2363	13	4	23		-	2	8	6	tr	2	-	-	-	-	22	-	-	2	5		13		2.68
2463	12	2	7		tr	tr	15	5	tr	tr	-	-	tr	-	35	2	tr	2	3		12		2.28

TABLE VI (cont.)

Tills on Oldman Formation (cont.)

Sample number	Heavy minerals, per cent (0.125 - 0.062 mm. fraction)																					Ratio hornblende to garnet
	Opaques																					
	Black	White	Others		Tourmaline	Zircon	Garnet	Epidote	Rutile	Sphene	Kyanite	Staurolite	Andalusite	Sillimanite	Hornblende	Orthopyroxenes	Clinopyroxenes	Apatite	Biotite		Others		
3163	5	3	10		1	tr	17	4	-	tr	-	tr	tr	-	39	3	tr	1	2		13		2.30
3763	19	5	16		tr	2	19	4	tr	1	-	-	-	-	18	2	-	1	tr		14		0.92
4163i	21	5	23		-	2	14	6	-	tr	-	tr	-	-	13	tr	-	tr	tr		15		0.90
4163ii	14	3	16		tr	1	10	6	-	tr	-	-	tr	-	34	-	tr	2	3		9		3.34
Tills on Foremost Formation																						
5862	13	6	14		-	tr	12	7	tr	3	-	tr	tr	-	24	-	-	3	5		11		2.02
10762	8	2	8		1	1	15	9	-	2	-	-	tr	-	41	1	-	1	3		8		2.76
11062	14	4	35		tr	tr	10	5	-	2	-	-	tr	-	17	tr	tr	tr	3		9		1.65
4263	19	5	15		-	2	11	7	-	tr	-	-	-	-	29	-	tr	1	tr		11		2.70
4363	26	4	7		tr	tr	19	8	-	2	-	-	-	-	20	tr	-	-	tr		13		1.03
4563	11	3	10		1	tr	13	5	tr	tr	-	tr	tr	-	45	-	-	1	2		7		3.50
4663ii	14	6	16		-	tr	12	8	-	3	-	-	-	-	28	-	-	2	tr		9		2.37
4763	12	5	11		tr	tr	14	7	tr	2	-	-	-	-	32	tr	-	tr	tr		13		2.21
4963	18	1	15		-	tr	14	7	tr	2	-	tr	tr	-	26	1	tr	2	1		10		1.86

TABLE VI (cont.)

Sample number	Heavy minerals, per cent (0.125 - 0.062 mm. fraction)																						Ratio hornblende to garnet
	Opaques				Tourmaline	Zircon	Garnet	Epidote	Rutile	Sphene	Kyanite	Staurolite	Andalusite	Sillimanite	Hornblende	Orthopyroxenes	Clinopyroxenes	Apatite	Biotite		Others		
	Black	White	Others																				
Tills on Eastend Formation																							
861	11	2	18		1	-	13	6	tr	tr	-	-	-	-	31	tr	tr	1	8		8		2.38
1361	11	3	16		tr	tr	19	10	1	2	-	tr	-	-	29	-	1	2	1		8		1.57
2361	11	1	12		tr	1	16	7	-	tr	-	-	-	-	37	2	tr	tr	tr		12		2.39
3461	11	3	16		tr	tr	14	6	-	1	-	-	-	-	35	-	tr	3	tr		10		2.51
3861	10	2	14		1	tr	16	5	-	3	-	tr	1	-	23	2	2	3	3		14		1.51
6061	7	1	8		1	-	19	5	tr	1	-	tr	1	tr	30	1	1	3	3		17		1.54
6461	13	2	9		1	1	14	3	-	2	-	-	-	-	37	3	tr	4	2		10		2.72
Tills on Frenchman formation																							
5761	11	2	9		tr	tr	15	12	-	1	-	-	-	-	31	4	tr	3	2		11		2.00
5861	9	4	9		1	tr	18	6	1	1	-	tr	1	-	28	3	2	tr	tr		15		1.50
Till on Pakowki formation																							
4863	22	3	21		tr	2	11	6	tr	2	-	-	-	-	17	tr	-	1	1		13		1.51
Till on Milk River formation																							
5163	17	3	16		-	1	8	8	-	3	-	tr	tr	-	25	1	tr	1	1		15		3.28
BEDROCK SAMPLES																							
Oldman fm.	2	2	9		-	-	1	tr	-	tr	-	-	-	-	-	-	-	1	79		4		-
Eastend fm.	14	25	6		1	tr	4	-	tr	2	-	-	-	-	tr	-	-	-	40		6		-
Frenchman fm.	14	11	19		tr	1	6	1	-	3	-	-	-	-	-	-	-	6	23		16		-

TABLE VII CARBONATE CONTENT OF TILL MATRIX

Tills on Bearpaw Formation

Sample number	Percentage dolomite	Percentage calcite	Percentage total carbonate (average)	Sample number	Percentage dolomite	Percentage calcite	Percentage total carbonate (average)
561*	5.5 6.5	1.3 1.5	7.4	11562	3.3 2.1	0.5 tr	3.0
2861	3.5 4.0	0.5 tr	4.0	1563	3.9 2.9	tr 1.2	4.0
5361	7.1 8.2	2.7 2.4	10.2	2663	1.8 2.2	tr tr	2.0
6961	7.7 7.2	1.9 2.0	9.4	2763	1.7 1.9	tr tr	1.8
7361	6.9 6.4	1.5 1.8	8.3	2863	2.8 2.6	0.6 0.6	3.3
7561	7.9 8.1	2.0 1.8	9.9	2963	1.4 0.6	tr tr	1.0
7961	6.1 5.7	1.9 2.2	8.0	3263	2.1 1.9	tr tr	2.0
8561	6.0 6.5	2.2 2.2	8.5	3363	2.7 3.0	tr tr	2.9
9361	6.2 5.9	1.9 1.7	7.9	3463	1.8 2.5	tr tr	2.2
1862	1.4 1.6	tr 0.2	1.6	3563i	1.5 tr	tr tr	0.8
2262	3.5 3.1	tr 0.3	3.5	3563ii	6.1 5.1	2.2 2.6	8.0
2862	4.8 4.5	0.5 0.1	5.0	3963i	3.8 4.0	1.5 1.0	5.2
10062	3.8 4.3	0.9 1.2	5.1	3963ii	4.1 5.0	2.3 2.6	7.1
10162	4.2 3.9	1.2 1.3	5.3				

* Duplicate runs were made on each sample

TABLE VII (cont.)

Tills on Oldman Formation

Sample number	Percentage dolomite	Percentage calcite	Percentage total carbonate (average)	Sample number	Percentage dolomite	Percentage calcite	Percentage total carbonate (average)
5362	3.5 3.6	0.8 0.8	4.4	1763	5.1 6.1	1.3 1.2	6.9
6762	6.3 5.9	1.3 1.2	7.4	1863	5.2 5.4	1.5 1.8	6.9
9962	6.5 6.1	2.6 1.9	8.6	1963	6.6 5.8	3.6 5.8	10.9
10462	3.9 4.1	0.8 0.1	4.5	2163	3.3 3.5	tr tr	3.4
10862	4.8 4.8	1.3 0.5	5.7	2363	1.2 2.6	tr tr	1.9
663	6.2 5.4	1.2 2.2	7.5	2463	4.4 4.5	1.5 1.6	6.1
863ii	4.9 4.6	1.2 1.2	6.0	2563	3.9 3.6	0.5 tr	4.1
963	8.2 8.5	2.8 2.4	11.0	3163	17.4 20.7	5.9 4.6	24.4
1063	5.2 4.8	4.8 5.1	10.0	3763	3.6 5.1	1.9 1.8	6.3
1263	5.5 5.1	1.7 1.9	7.1	4163i	5.2 4.9	1.2 1.5	6.5
1363	4.5 4.1	1.9 1.4	6.0	4163ii	5.0 4.9	1.6 1.6	6.6
1463	5.8 4.9	1.2 1.3	6.7				

TABLE VII (cont.)

Tills on Foremost Formation

Sample number	Percentage dolomite	Percentage calcite	Percentage total carbonate (average)	Sample number	Percentage dolomite	Percentage calcite	Percentage total carbonate (average)
5862	6.2 5.6	0.4 1.0	6.6	4663i	5.9 7.4	0.8 1.5	7.9
10762	6.3 5.9	1.5 1.8	7.8	4663ii	3.4 3.6	1.2 1.5	4.9
4263	4.7 5.0	1.4 1.6	6.4	4763	5.6 7.0	2.2 2.5	8.7
4363	1.8 4.6	1.7 1.6	4.9	4963	4.5 4.6	1.9 2.1	6.6
4563	4.8 3.0	1.2 tr	4.5				

Tills on other bedrock formations

3461	5.9 5.8	2.4 2.0	8.1	4863	6.0 4.6	2.2 3.3	8.1
5861	13.6 14.5	4.6 4.7	18.7	5163	5.6 5.0	2.3 2.6	7.8
6061	8.8 8.5	2.2 2.5	11.0				

BEDROCK SAMPLES

Bearpaw formation 161	-	1.4	1.4	Eastend formation 2061	-	0.2	0.2
Oldman formation 9162	15.6	tr	15.6	Frenchman formation 8862	-	tr	tr

CHAPTER VII - THE LAURENTIAN ICE SHEETS: MAXIMUM THICKNESS AND DIRECTIONS OF MOVEMENT IN MAP-AREA

Surface gradients and maximum thickness of glaciers

In the map-area and its immediate vicinity, three nunataks projected above the surface of the ice sheet at the time of the most extensive Laurentian glaciation. In Alberta, the Cypress Hills formed a nunatak 120 square miles in area and approximately 300 feet high. The Sweet Grass Hills, just south of the International Border, stood as great nunataks 2000 feet above the ice (Calhoun, 1906), and the Del Bonita Upland, west of the map-area (township 1, ranges 21 and 22), formed the other nunatak (Stalker, G.S.C. map 41-1962).

The maximum elevation of erratics on these uplands corresponds approximately to the maximum altitude of the surface of the ice sheet at the time of the most extensive Laurentian glaciation. The northern slopes of the Cypress Hills were glaciated up to a height of 4500 feet above sea level. The highest glacial drift that was observed lies in section 29, township 8, range 1, where 8 feet of glacial gravel sits on the Cypress Hills formation. The southern slopes were not glaciated above 4050 feet (Elkwater Sheet). According to Alden (1932), at the western end of the Sweet Grass Hills, glacial drift occurs 4800 feet above sea level but does not occur above 4350 feet at the eastern end of the hills. Farther to the west, on the Del Bonita Upland, erratics are present up to 4550 feet above sea level (Stalker, 1963, personal communication). Thus, during the most extensive Laurentian glaciation, the regional slope of the glacier's surface from the Cypress Hills southward to the eastern end of the Sweet Grass Hills was to the south at about 3 feet per mile. Between the Cypress Hills and the Del Bonita Upland, the glacier's surface must have been almost horizontal. Locally, around the Cypress Hills, the surface gradient of the

glacier steepened to about 45 feet per mile (that is, about 1/2° slope). The Highwood Mountains of Montana, 100 miles south of the map-area, were glaciated up to 4200 feet (Calhoun, 1906), and indicate that small surface gradients of the glacier persisted south of the map-area. The occurrence of glacial drift 4800 feet above sea level at the western end of the Sweet Grass Hills (Alden, 1932) does not fit in with the maximum elevations of erratics in adjacent areas and in the above discussion this observation has been ignored.

Over most of the map-area, therefore, the maximum altitude reached by the continental glaciers was about 4500 feet, decreasing to about 4300 feet in the southeast. At this time, the ice was 2300 feet thick at Medicine Hat, about 1500 feet thick at Foremost and Manyberries, and approximately 1000 feet thick at Aden (Map 1).

Directions of ice movement in map-area

Glacial lineaments, petrofabric analysis of till, sole marks on till sheets, streamlined land forms and indicators have all been used to determine the directions of ice movement in the map-area.

Glacial lineaments are best developed in the western half of the Foremost-Cypress Hills area, where, for the most part, the relief is small. They are rare in the dissected Cypress Hills Upland (Map 1). The common alignment of glacial lineaments parallel to ice-marginal channels and perpendicular to flutings shows that the dominant lineament trend parallels former positions of the ice front. The glacial lineaments and end moraines on Map 1 clearly show the influence of local topography on the directions of ice movement and configuration of the ice front. Thus, in the western part of the map-area, the glaciers moved southward, but farther east they were forced to flow southeastwards along the stretch of low land between the Cypress Hills and Sweet Grass Hills. This southeasterly movement is well recorded by flutings, drumlins, drumlinoid ridges, and, in township 5, range 2, by numerous blocks of

Cypress Hills conglomerate (Plate 27D) that could only have come from the north-northwest (Map 10).

Where glacial lineaments are not well developed, as in the vicinity of the Cypress Hills, till fabric studies were conducted to find out the local directions of ice movement. It has long been known that stones in till have a preferred orientation (Miller, 1884). Richter (1932), however, was the first person to realise that stones in till tend to have their long axes aligned parallel to the direction of ice movement. He came to this conclusion after observing striations on elongate tillstones parallel to the long axes of these stones (Plate 26). Hence, if the long-axis orientation of a number of stones in till at a certain locality is plotted on a rose diagram, the preferred orientation obtained is parallel to the direction of ice movement at that spot.

Oriented till blocks were collected in the field and the azimuth of the long axis of each stone was measured in the laboratory with a contact goniometer. Figure 26 suggests that 50 measurements will give the preferred orientation of the stones. One hundred measurements were made on each sample that was studied in the laboratory, but when measurements were made directly in the field, using a Brunton, they were limited to 50. The results are shown in Figure 27 and Map 1. Most of the rose diagrams display a distinct preferred orientation of the long axes of the tillstones. The stones in till 3963(ii), however, have no preferred orientation. At several localities, glacial lineaments are aligned perpendicular to the long-axis orientation of the tillstones (Figure 27). This confirms the latter orientation as being parallel to the direction of ice movement, for most glacial lineaments parallel former positions of the ice front.

Petrofabric analysis of a till southwest of the Cypress Hills (561) indicates ice movement towards the southeast, agreeing with the direction given by other data in this area (see above). Generally speaking, north of the Cypress Hills, the glacier

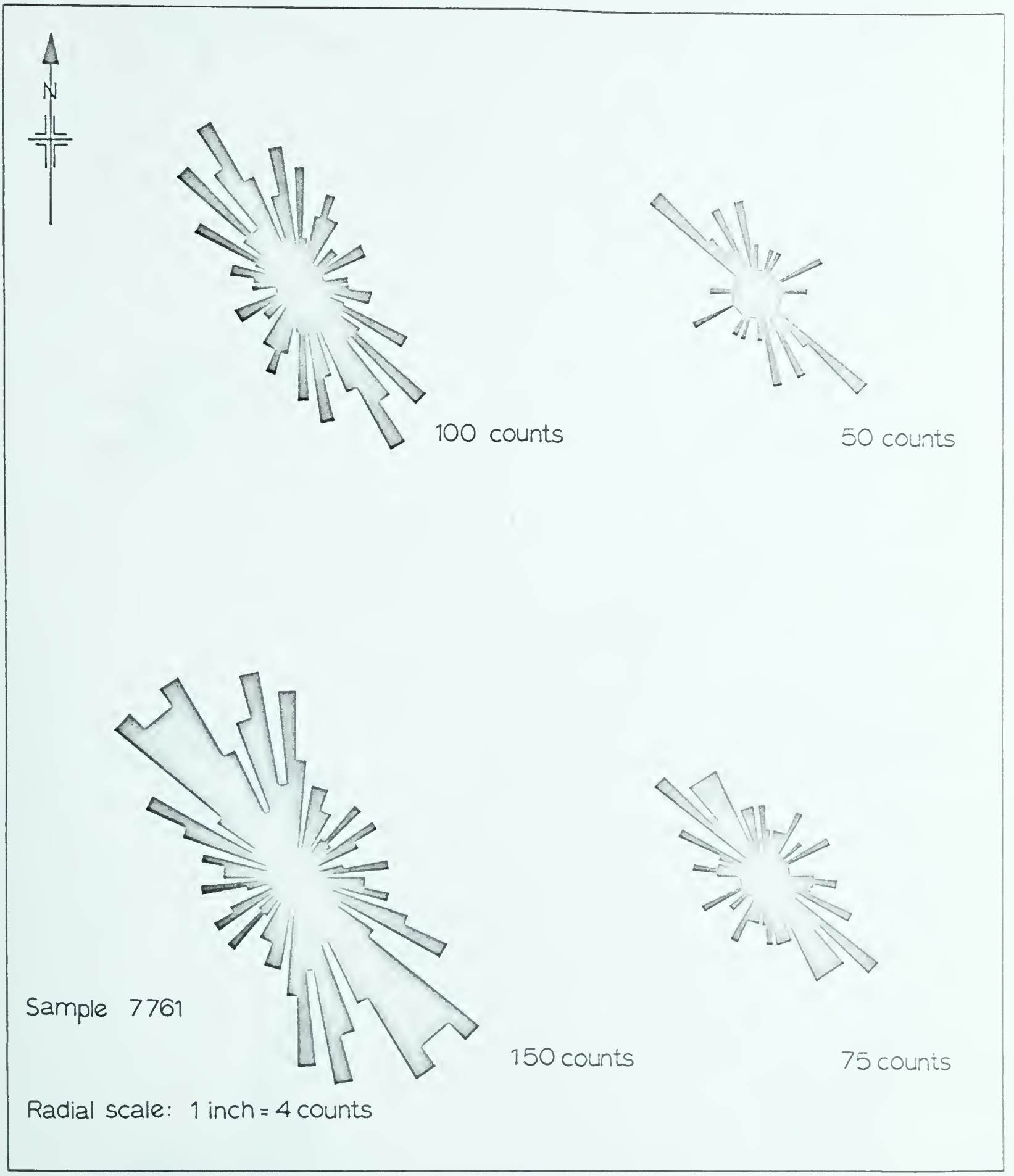
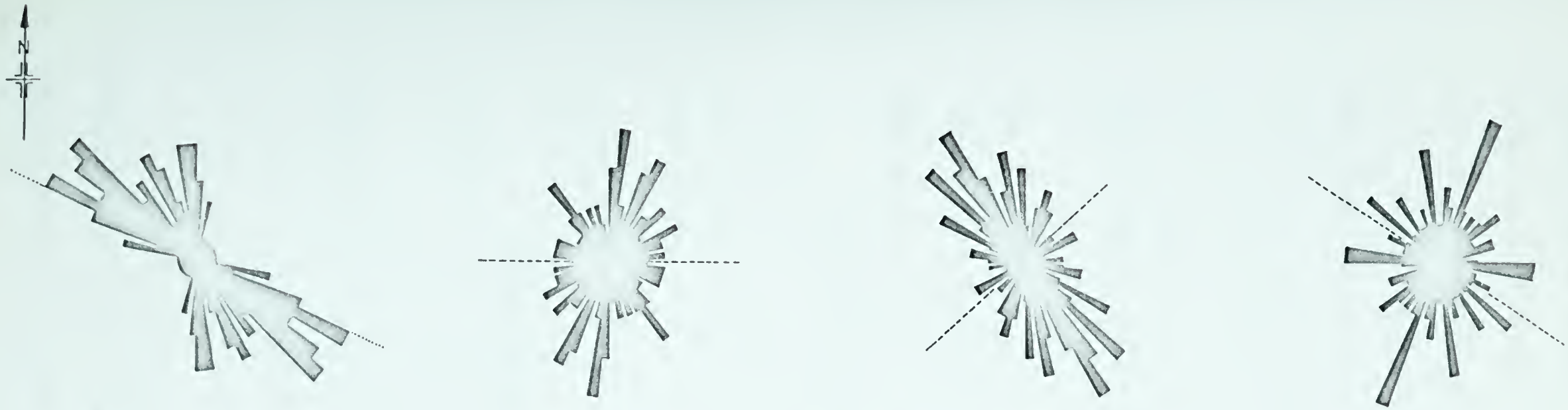
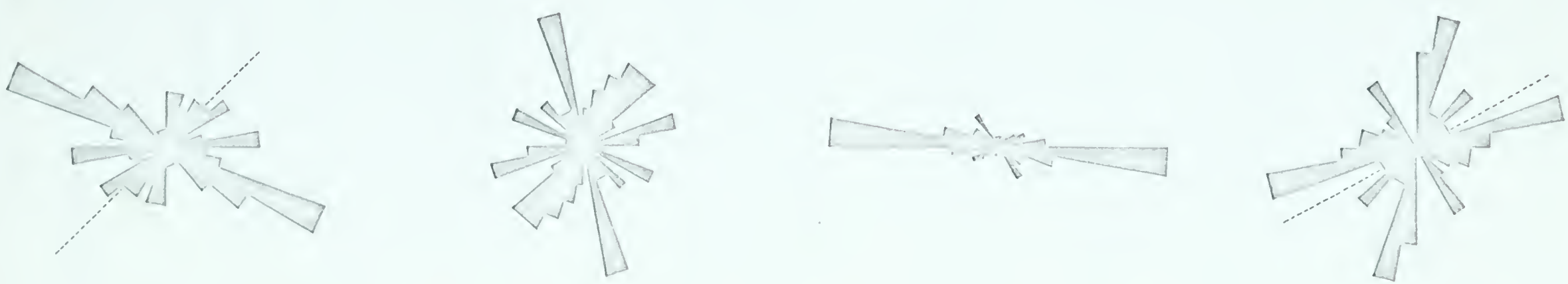


Figure 26. Variation of the estimated preferred long-axis orientation of stones in a till sample as the number of measurements are increased



Sample 561 7361 7761 9761



Sample 1063 3763 3963 (i) 3963 (ii)

Figure 27. Rose diagrams showing long-axis orientation of stones in tills (see next page for explanation)

that deposited the Pakowki End Moraine (Figure 32) flowed to the south, deviations from this direction being caused by the local topography (7361, 7761, and 9761), while later, less extensive glaciers moved into the map-area from the northwest (4063).

At one locality (section 1, township 12, range 11), ice movement towards the southeast is indicated by sole marks on the bottom of the surface till sheet (Plate 27B; Map 1). Glacial lineaments in the area agree with this direction of ice movement and show that it was localised at the southeastern end of a small ice lobe which extended into the northwestern corner of the map-area. The sole marks, composed entirely of till, consist of parallel ridges on the bottom of the till sheet. They were formed when the glacier overran and deformed the underlying frozen sands (Plate 27A). At this time, the surface of the sand was furrowed by the scratching action of rock fragments at the base of the glacier, and, as the glacier continued to move, till was smeared into these linear furrows.

Where sand inclusions exist in till, a lineation may be present at the till-sand contact. In sample 561 (Figure 27 and Plate 27C) this lineation is parallel to the long-axis orientation of the tillstones, and hence is parallel to the direction of ice movement.

Figure 27.

Rose diagrams showing long-axis orientation of stones in tills

Top row: 100 counts were made on each sample. Rose diagrams have 5° cells with a radial scale of 1 inch equals 4 counts.

Bottom row: Measurements taken in the field; 50 counts at each locality. Rose diagrams have 10° cells with a radial scale of 1 inch equals 4 counts, except 3963(i) which has 1 inch equals 8 counts.

Measurements from surface till, except in 3763 and 3963(i).

Dotted line (561) marks orientation of lineation on bottom of till block (Plate 27C).

Dashed line indicates orientation of glacial lineaments near sample locality.

Regional directions of ice movement

Dolomite- and limestone-rich tills exist in the map-area (Figure 21 and Tables IV and V) but are absent in central and eastern Alberta. This observation prompted an enquiry by the writer into the significance of the change in erratic pebble composition of the tills in Alberta with respect to the regional directions of ice movement in the Western Prairies. Data on the pebble composition of tills in eastern Alberta were obtained from the Soil Survey Division, Research Council of Alberta. Unfortunately, no such information was available from Saskatchewan (Kupsch, 1964, personal communication).

The erratic pebble composition of tills together with other relevant data on ice-movement directions are shown in Figure 28, out of which arise several important facts.

Ice-flow markings indicate a southerly flow of ice, parallel to the Rocky Mountain Front, in central and southwestern Alberta at the time of the last major glacial advance (Stalker and Craig, 1956). The erratic pebble content of the surface tills in eastern Alberta, however, cannot be explained by movement in this direction. From the Cold Lake area south to Medicine Hat, there is a dilution of orthoquartzite, accompanied by an increase in dolomite and limestone. A sudden and striking increase in carbonate pebbles occurs near Medicine Hat. A large area of orthoquartzite (Athabasca sandstone) exists south of Lake Athabasca, and extensive outcrops of Palaeozoic carbonate rock occur southeast of Lac la Ronge (Figure 28). Thus, the changes in erratic pebble composition of the surface tills in eastern Alberta are best explained by ice moving into this region from the northeast. The carbonate-rich tills at Medicine Hat and around the Cypress Hills were most probably deposited from ice that crossed the wide belt of Palaeozoic rocks just southeast of Lac la Ronge. This means that the last major Laurentian glacier advanced into Alberta flowing in a general direction S. 35°-40° W. This agrees with the ideas expressed in the early

LEGEND

PALAEOCENE AND EOCENE

9 Sandstone, shale; conglomerate; coal

UPPER CRETACEOUS

8 Shale, sandstone, conglomerate; coal, bentonite

LOWER CRETACEOUS

7 Sandstone, shale, conglomerate, coal, tar sand

TRIASSIC

6 Argillite, quartzite, limestone, volcanic rocks

DEVONIAN

5 Shale, limestone, dolomite, conglomerate, sandstone, salt

SILURIAN

4 Sandstone, shale, limestone, dolomite, conglomerate, salt

ORDOVICIAN

3 Limestone, dolomite, shale, argillite, sandstone, quartzite

LATE PROTEROZOIC

2 Sandstone, quartzite, conglomerate, shale

ARCHAEAN AND/OR PROTEROZOIC

1 Mainly acid rocks granodiorite, granite, quartz diorite, granite gneiss - includes much granitised sedimentary and volcanic rock

Drumlin groups, crag and tail features, giant glacial grooves Orientation parallels direction of ice movement. Arrowheads used only where sense of direction is clearly indicated

Generalised directions of ice movement during advance of last major glacier

Outer limit of significant glacial advance

Area not glaciated by Laurentian ice

Lacustrine sediments deposited in lakes dammed by glacier ice

Erratic pebble composition of surface tills
A, igneous and metamorphic rocks, B, limestone and dolomite, C, orthoquartzite
a, 2 samples, b, 16 samples, d, 26 samples, Alberta Soil Survey c, 20+ samples, Bayrock, 1960 e, present report f, 20+ samples, Howard, 1960

Foremost-Cypress Hills area

Willow Bunch Lake area (Panzek, 1961)

Bedrock geology taken from GSC map 1045A, 1955, and information on the glacial geology taken from Glacial Map of Canada, 1958, and Glacial Map of the United States East of the Rocky Mountains, 1959

FIGURE 28 DIRECTIONS OF ICE MOVEMENT, ERRATIC PEBBLE COMPOSITION OF TILLS, AND BEDROCK GEOLOGY OF THE WESTERN PLAINS OF CANADA AND CONTIGUOUS PARTS OF THE UNITED STATES

literature and with Gravenor and Bayrock (1955), but argues against a southeasterly direction of movement across eastern Alberta and central Saskatchewan that was proposed by Stalker and Craig (1956). The tills in northeastern Montana and northwestern North Dakota contain even more carbonate pebbles than those in southeastern Alberta, again indicating an overall advance of the last glacier from the northeast (Lemke, 1960, p. 111; Howard, 1960, p. 41).

In some areas, the topography exerted a considerable influence on the directions of ice movement. The southerly movement of ice parallel to the Rocky Mountain Front in western Alberta is one example. The Tertiary uplands of southern Saskatchewan and southeastern Alberta prevented the southwestward movement of a large volume of ice into Montana, which resulted in the strong southeasterly sweep of the glaciers at the western end of these Tertiary uplands and a corresponding southwesterly sweep at the eastern end (Figure 28). This is the reason for the relatively low unglaciated area of Wood Mountain (Wickenden, 1931, p. 47).

CHAPTER VIII - PLEISTOCENE STRATIGRAPHY

Historical Review

The Pleistocene deposits of southern Alberta and adjacent parts of Saskatchewan and Montana have been studied by several workers since the late 19th Century. Their respective stratigraphical ideas are summarised below in chronological order. Some of the time-stratigraphical terms used in the older reports are no longer in use or have changed their meaning: where such terms are mentioned the modern equivalent is inserted in parentheses. The stratigraphical column of the Pleistocene Series in central North America is given in Figure 29.

Dawson and McConnell, working mainly in southwestern Alberta, distinguished four major stratigraphical units (Dawson, 1885, 1890, 1891, 1895; Dawson and McConnell, 1895). The lowermost one is a Cordilleran till sheet that grades eastwards into outwash gravels, named "Saskatchewan gravels" by Dawson. This is the Albertan (Nebraskan) drift of Dawson and McConnell. A Laurentian till sheet ("lower boulder clay"), of Kansan age, overlies the Albertan drift and is itself capped by lignite-bearing interglacial beds of Yarmouth age. The uppermost unit is another Laurentian till sheet ("upper boulder clay"), more widespread than the lower till, and of Iowan (Lower or preclassical Wisconsin) age. Dawson and McConnell believed Wisconsin (classical Wisconsin) drift to be absent west of the Missouri Coteau.

Calhoun's (1906) stratigraphical interpretation was very different. He studied the Pleistocene deposits of northern Montana and concluded that the quartzite gravels (equivalent to Dawson's "Saskatchewan gravels"), were deposited by streams in "pre-Glacial" time. They were not glacial gravels but represented deposits reworked from Tertiary gravels occurring at higher elevations. The fresh morainal

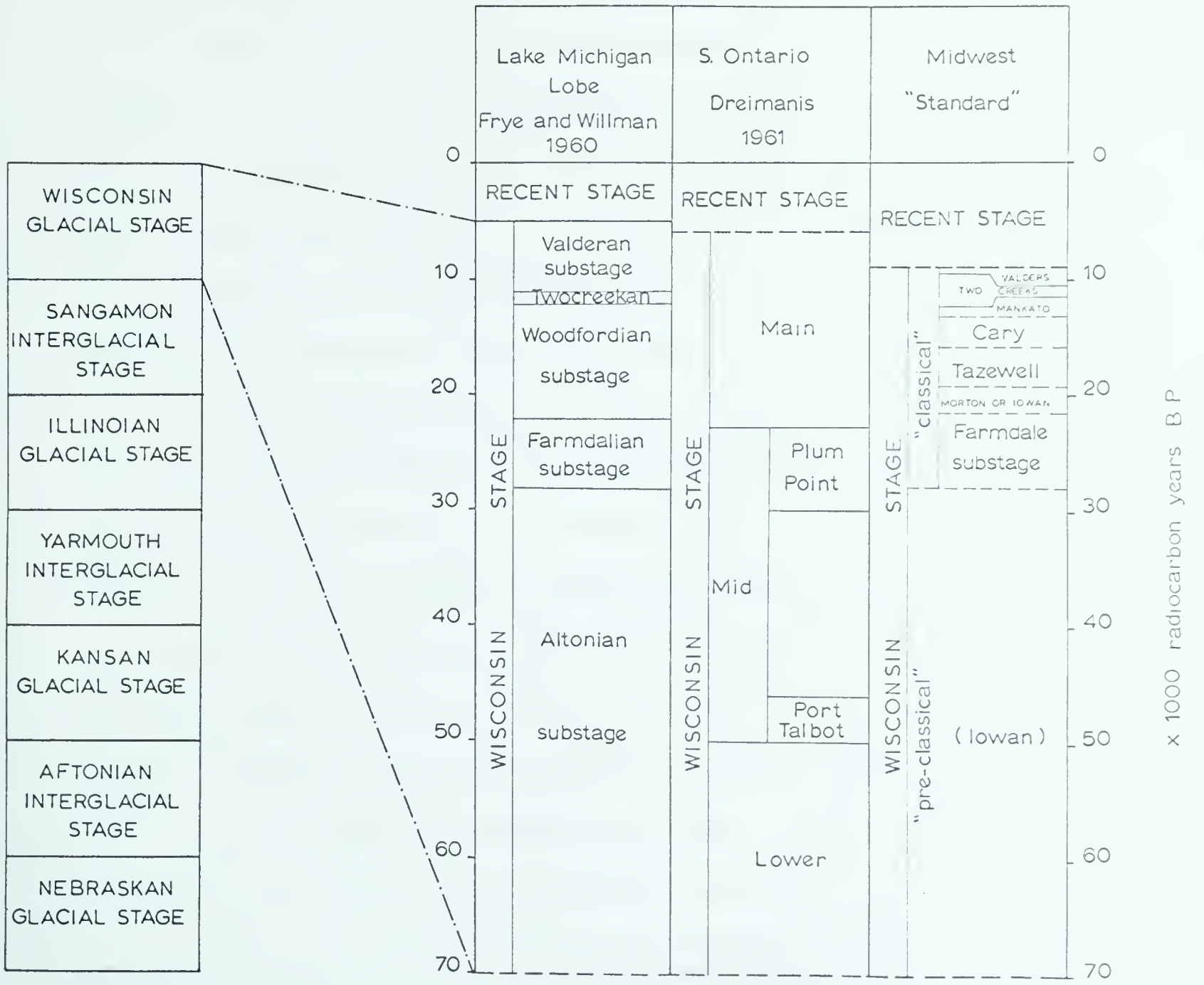


Figure 29. Stratigraphic column of the Pleistocene Series in Central North America

topography of the surface Laurentian drift, the amount of postglacial erosion and degree of weathering led Calhoun to believe that this till sheet was of late Wisconsin (late classical Wisconsin) age. He found meagre evidence of an older Laurentian drift and also recognised a pre-Wisconsin Cordilleran drift.

Johnston and Wickenden (1931) recognised the same stratigraphical units in southern Alberta as Dawson and McConnell -- namely the "quartzite river gravels," two tills of the northeastern ice sheet and one set of interglacial deposits. They assigned a Kansan age to the lower, more extensive till and thought the upper till to be of early Wisconsin (classical Wisconsin) or Illinoian age. The interglacial beds represented the time interval between these two till sheets.

According to Alden (1932), the oldest till sheet in Montana was deposited on the Flaxville Plain and No. 2 Bench (see Chapter III) by glaciers from the Rocky Mountains in early Pleistocene time. Alden recognised equivalents of Dawson's "Saskatchewan gravels" in Montana, and believed them to be pre-Iowan (pre-Wisconsin) or pre-Illinoian in age, possibly representing either the Sangamon or Yarmouth Stage. He thought that this gravel was either derived directly from the mountains to the west or that it was let down by erosion from older deposits on the higher levels of the plains and redeposited by streams. Alden's comments on the age of the lower till of the northeastern ice sheet are as follows (Alden, 1932, p. 69):

> "There seems to be no clear evidence that the Keewatin ice sheet invaded Montana at either the Nebraskan or the Kansan stage of glaciation. Neither is it certainly known that there was extensive development of the Keewatin glacier at the Illinoian stage, when the Labradorean ice sheet extended southwestward over most of Illinois and encroached on southeastern Iowa. After the Sangamon stage of deglaciation, however, there came on a new development and extension of the great Keewatin ice sheet centering in the Hudson Bay region. The ice spread southward across Minnesota into northern Iowa and left a deposit of drift of moderate thickness, which has been regarded as of pre-Wisconsin age but not so old as the Illinoian drift of the Labradorean ice sheet. There are some good reasons, as it seems to the writer, for thinking that the drift found in the Dakotas and in Montana, outside what is regarded as the limit of the Wisconsin drift, is not older than the Iowan drift. It is possible, however, that it is really of Illinoian age."

Following an interval during which a moderate amount of erosion of the Illinoian or Iowan (Lower or preclassical Wisconsin) drift was accomplished, the upper till of the northeastern ice sheet was deposited in early or middle Wisconsin (classical Wisconsin) time. In the western part of Montana these Laurentian tills are interbedded with Cordilleran tills.

Horberg (1952) identified three Laurentian drift sheets in the Lethbridge region of southern Alberta and tentatively correlated them with the Iowan (Lower or preclassical Wisconsin), Tazewell and Cary Substages of the Wisconsin Stage (Figure 29). He considered the "interglacial" beds of previous writers, which he called "Lenzie silt", to be proglacial lake beds deposited in front of the retreating Tazewell or Cary ice sheet and suggested that the lignite and peaty material reported from this horizon by Dawson (1885, p. 152c) and Johnston and Wickenden (1931, pp. 32-33) was not primary. Horberg believed the "Saskatchewan gravels" to be nonglacial in origin and probably of late Tertiary age.

Recent work on the stratigraphy of the Pleistocene deposits in southwestern Alberta has been done by Stalker (1963b). In short, he assigns an early Pleistocene age to the "Saskatchewan gravel and sand", recognises Laurentian and Cordilleran tills of Nebraskan(?), Kansan(?), Illinoian(?), and Wisconsin age, and suggests that the wood-bearing interglacial beds first described by Dawson (1885), are Yarmouthian (Stalker, 1963b, p.7). Stalker noted that large bedrock masses were present beneath the latter horizon.

Divergent stratigraphical interpretations of the Pleistocene deposits of southern Alberta and adjacent areas exist, therefore, but it is of interest to note that the geologists of the United States (Calhoun, Alden, and Horberg) regarded the Laurentian tills as Wisconsin or Illinoian(?) in age whereas the Canadian geologists believed most of these tills to be considerably older.

Stratigraphy of the Pleistocene deposits in the Foremost-Cypress Hills area

The stratigraphical column of the Pleistocene deposits in the Foremost-Cypress Hills area is shown on Figure 30. The Saskatchewan gravels and sands and overlying proglacial lacustrine sediments, Manyberries volcanic ash, and Cypress Hills loess are all rock-stratigraphical units. The drifts (described below), however, are not rock-stratigraphical units as defined by the American Commission on Stratigraphic Nomenclature (1961, Art. 4) because they have been differentiated by their topographical form, geographical position, and inferred geological history. They are morphostratigraphic units, defined by Frye and Willman (1960, p. 7) as: "..... a body of rock that is identified primarily from the surface form it displays; it may or may not be distinctive lithologically from contiguous units; it may or may not transgress time throughout its extent." Frye and Willman (1962, pp. 112-113) took the moraine as the basic unit "and the deposits assigned to it include those of the end moraine that gives it identity, the associated outwash apron, if one exists, and the drift continuing into the associated ground moraine." Clayton (1962, p. 53) considered the basic unit a drift rather than a moraine, and defined a morphostratigraphic unit as "a body of drift that is identified by its surface form and position and consists of all the drift deposited from the glacial ice and associated meltwater of a significant glacial advance."

Saskatchewan gravels and sands

The Saskatchewan gravels and sands were first recognised by McConnell (1885) who called them "South Saskatchewan gravels" and they were subsequently noted in various parts of the plains of western Canada by Tyrrell (1886), Dawson (1895) and Coleman (1909) and in Montana by Calhoun (1906), Alden and Stebinger (1913), and Alden (1932). Rutherford (1937) studied these sediments in central Alberta and used the term "Saskatchewan gravels and sands" as he found that sand

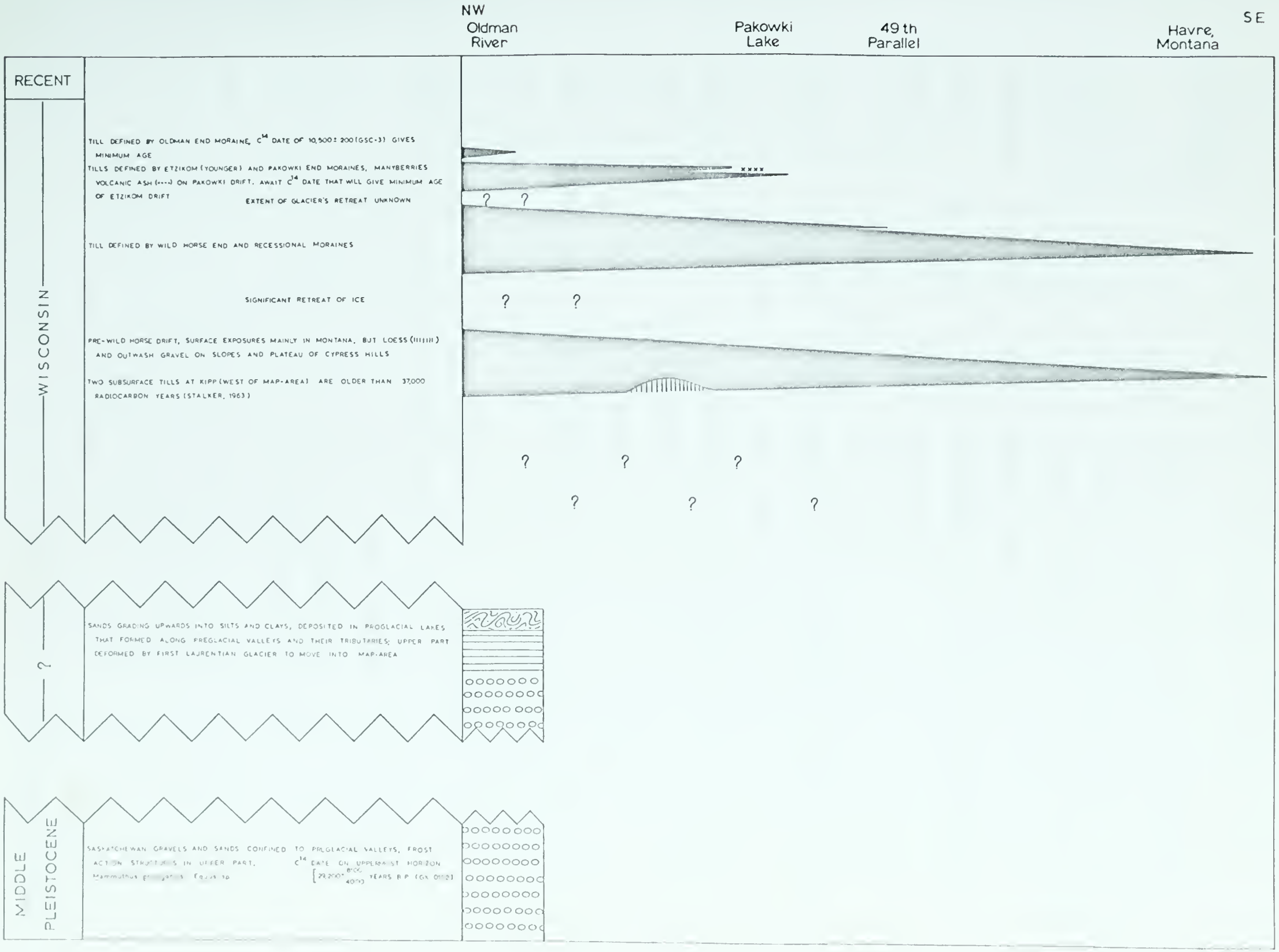


Figure 30. Transverse diagram of Pleistocene deposits of the Foremost-Cypress Hills area

was commonly the dominant constituent. This designation will be used in the present report.

In the map-area, the Saskatchewan gravels and sands lie unconformably upon Upper Cretaceous rocks and are invariably covered by glacial drift. They floor preglacial valleys and outcrops occur along the Oldman River Valley and the South Saskatchewan River Valley below Medicine Hat (see Appendix C for description of sections). These gravels and sands undoubtedly occur in the Ancestral Milk River Valley but are covered by 200 feet of glacial drift.

Quartzite (including quartzitic sandstone and conglomerate), argillite, arkose, and chert pebbles make up the bulk of the Saskatchewan gravels and sands (Figure 31), but limestone, and volcanic rocks do occur together with bedrock fragments of local derivation. The absence of material from the Canadian Shield is notable. Most of the quartzite pebbles are red or brown and many are stained by ferric oxide, giving an overall reddish-brown colour to the sediment. The source region of these gravels is the Cordilleran area to the west (Dawson, 1895; Calhoun, 1906; Alden, 1932; Horberg, 1952), although significant contributions most probably came from the gravel-capped elevated remnants of Tertiary peneplains (McConnell, 1885; Calhoun, 1906; Alden, 1932; Rutherford, 1937).

Structures produced by frost action were observed in the Saskatchewan gravels and sands that are exposed along the Oldman River Valley. Involutions occur at Lsd.12 S.20 Tp.11 R.14 and deranged pebbles at Lsd.6 S.23 Tp.11 R.15 (Plate 28, A and B). In places these structures are overlain by undisturbed Saskatchewan gravels and sands (Plate 28, B), suggesting that at least the uppermost horizons of this deposit accumulated in a periglacial environment. Similar structures have been observed by Westgate and Bayrock (in press) in the Saskatchewan gravels and sands of central Alberta. They likewise conclude that the uppermost horizons were deposited in a periglacial environment.

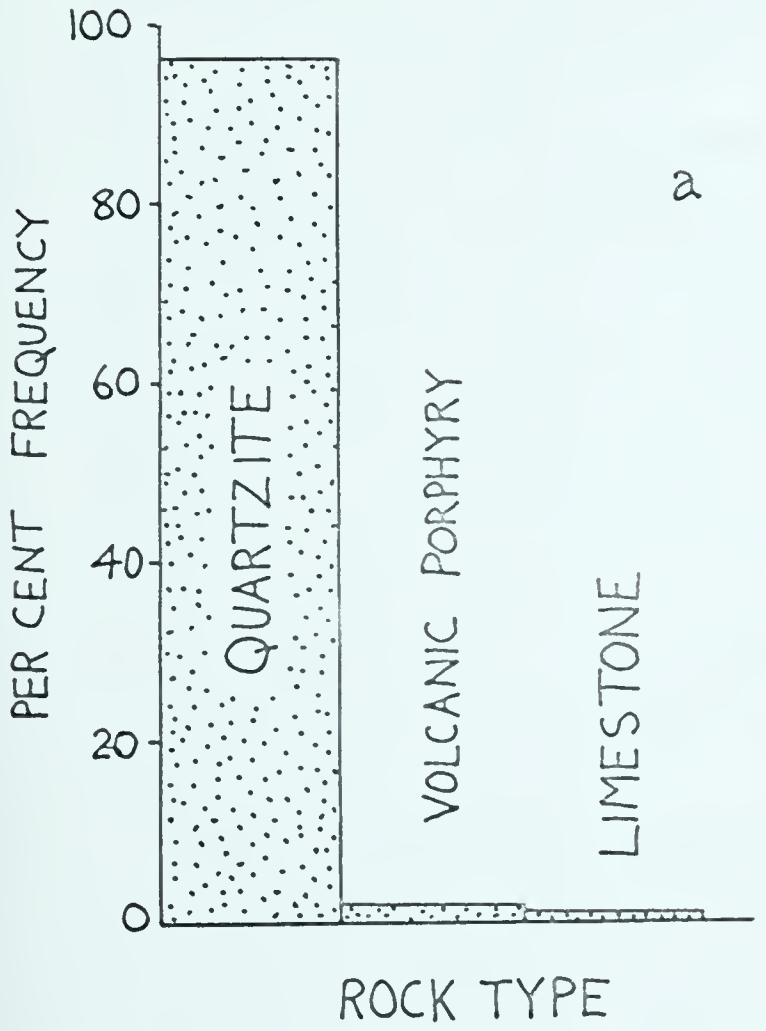


Figure 31. Pebble composition of Saskatchewan gravels and sands

a. Oldman River Valley (Lsd. 6, S. 23, Tp. 11, R. 15, W. 4): "Quartzite" category includes black chert; 879 pebbles counted.

b. South Saskatchewan Valley (Lsd. 4, S. 17, Tp. 13, R. 5, W. 4): "Others" include arkose and volcanic porphyry; 202 pebbles counted.

Decidedly divergent views have been expressed on the age of the Saskatchewan gravels and sands and on the nature of the climate that existed at this time (see above). The presence of frost action (periglacial) structures, however, indicates a Pleistocene age. The occurrence of remains of Mammuthus primigenius (woolly mammoth) in these gravels points to the same (see Appendix C) and supports the contention that at least the upper part of the Saskatchewan gravels and sands accumulated in a periglacial environment. A radiocarbon date of $29,200 \pm \frac{8100}{4000}$ years B.P. (GX-0102)[1] was obtained on partially carbonised wood from the upper part of the Saskatchewan gravels and sands that are exposed along the South Saskatchewan Valley at NE 1/4 S.9 Tp.13 R.5, just north of Medicine Hat. At this locality, sand is the dominant constituent of the Saskatchewan gravels and sands, which are overlain by 40 feet of silts and sands (capped by a thin clay bed) that were deposited in a proglacial lake which formed along the Ancestral Milk River Valley as a result of damming downstream by glacier ice. Three feet of till and a thin glacial gravel bed sit on these lacustrine deposits and are covered by 40 feet of similar lacustrine silts. These in turn are overlain by 20 feet of greyish-brown massive till. If this radiocarbon date is accepted, the upper part of the Saskatchewan gravels and sands is of Middle Wisconsin age, in the chronology of Dreimanis (1960), and as these sediments are preglacial, it follows that the first Laurentian glacier did not enter southern Alberta until Middle Wisconsin time. In other words, in southeastern Alberta, the time interval in which these non-glacial gravels were deposited --

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[1] "The sample was treated with hot dilute HCl and hot dilute NaOH to remove carbonate and alkali-soluble material prior to analysis. The large error is primarily due to the sample size which should have been larger for such old material." (Geochron Laboratories)

those that floor the preglacial valleys and cover their alluvial terraces--represents most of the Pleistocene Epoch.

Sediments deposited in proglacial lakes that formed along preglacial valleys and their tributaries prior to glaciation

As the first Laurentian glacier advanced towards the map-area it blocked the outlets of rivers that drained into the Hudson Bay (Figure 7). This resulted in the ponding back of waters along the preglacial valleys and their tributaries, forming elongate proglacial lakes. Sands, silts, and clays were deposited in these lakes. They conformably overlie the Saskatchewan gravels and sands in the main valleys but along the tributary valleys usually sit directly on bedrock (e.g. Bullshead Creek section - Appendix C). Along the Oldman River Valley, near Wolf Island, these lacustrine sediments are 20 feet thick, but at other places along this valley they have been completely eroded away. McConnell (1885, p. 71c) gives a thickness of 150 feet of fine sand and silt above the Saskatchewan gravels and sands near to where the South Saskatchewan River enters the Red Deer River. In the map-area, the upper part of these sediments, which are commonly varved, was deformed by the overriding glacier (Plate 28,C). As these sands, silts, and clays conformably overlie the Saskatchewan gravels and sands--there being no evidence of a prolonged break in sedimentation--the radiocarbon date on the upper horizon of the Saskatchewan gravels and sands (see above) gives the approximate maximum age of these lacustrine deposits. Too much confidence cannot be placed in this one date, however; more dates from this horizon are forthcoming and we must await these before definitive statements can be made.

Glacial deposits

Five surface drift sheets (morphostratigraphic units) have been identified in the Foremost-Cypress Hills area. All were deposited by Laurentian ice. Their

respective end moraines are shown on Figure 32, each representing a significant glacial advance. They are, in order of decreasing age, the pre-Wild Horse drift, Wild Horse drift, Pakowki drift, Etzikom drift, and Oldman drift. The fresh-looking morainal topography, absence of severely weathered horizons, and the radiocarbon date on the upper part of the Saskatchewan gravels and sands suggest that all these surface drifts belong to the Wisconsin Stage (Figure 30). As yet radiocarbon dates are too few to allow these several drift sheets to be assigned to a particular Wisconsin substage.

Pre-Wild Horse drift In the map-area, the pre-Wild Horse drift is confined to the Cypress Hills and its immediate vicinity (figures 28 and 32). It is thin and consists of sporadic patches of glacial gravel and till on the slopes of the Cypress Hills together with erratics, including a pinkish dolomite. The Cypress Hills loess belongs to this drift sheet (Figure 30).

This is the oldest surface drift sheet in the map-area, but the persistence of carbonate erratics at the surface suggests that it belongs to the Wisconsin Stage (that is, it never experienced an interglacial). The relationship of the end moraines in the map-area to those in Montana (Figure 28) shows that the pre-Wild Horse drift correlates with the southernmost drift sheet in Montana which was regarded as "Iowan" by Alden (1932) and Horberg (1952). Whether older less extensive drifts occur beneath the pre-Wild Horse drift in the Foremost-Cypress Hills area is not known. Stalker (1963b) has identified two tills greater than 37,000 years old (L433, L455) near Lethbridge, just west of the map-area. This date, however, conflicts with the radiocarbon date on the Saskatchewan gravels and sands (GX-0102). Clarification on this point will be achieved as more radiocarbon dates become available.

Wild Horse drift Wild Horse drift drapes the greater part of the Cypress Hills Upland, the Sweet Grass Hills Upland, and covers the southeastern corner of

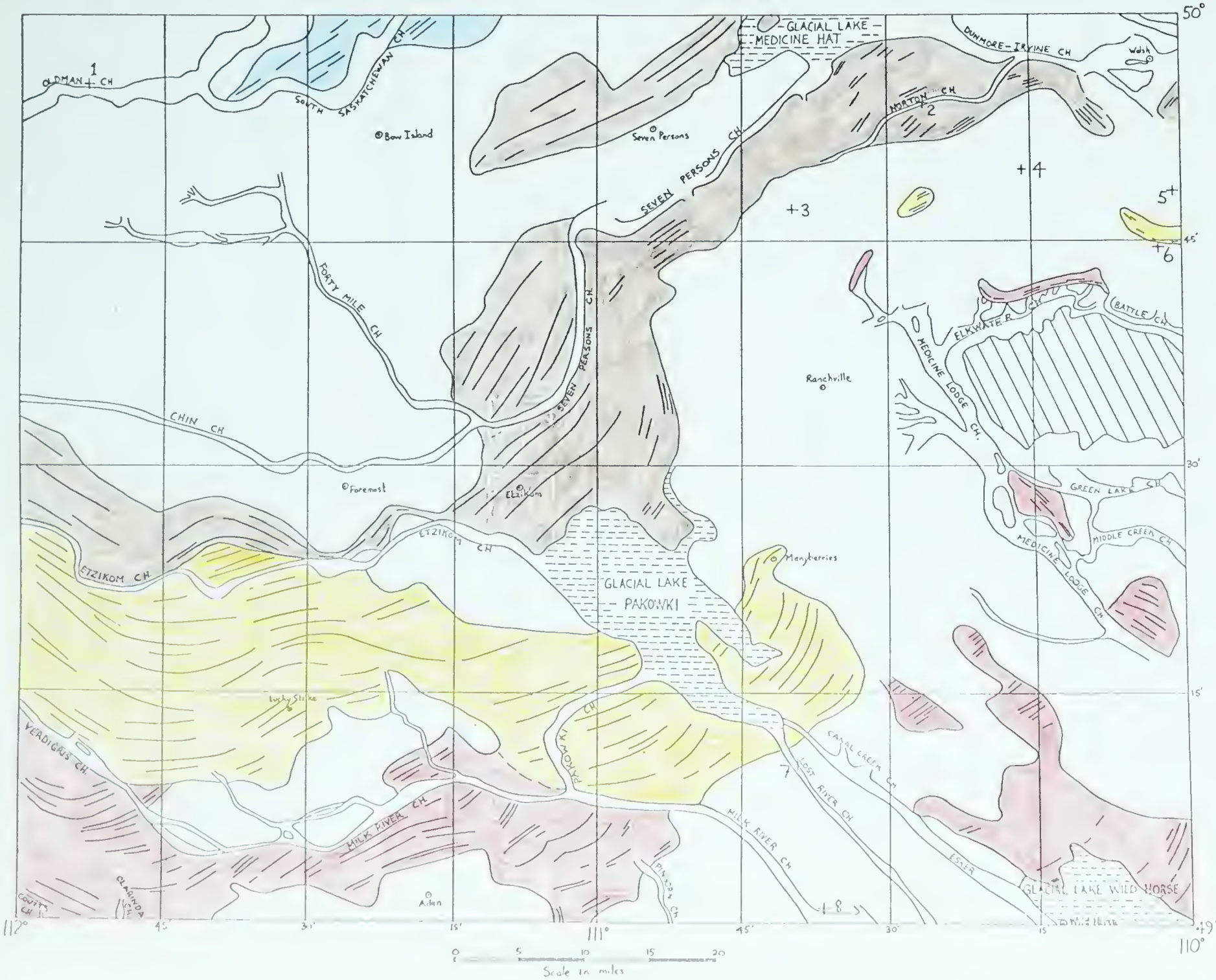


Figure 32. End moraines of the Foremost-Cypress Hills area

the map-area (figures 28 and 32). It lies, for the most part, on the Bearpaw, Oldman, and Pakowki formations and has a clay-loam to loam texture (Figure 15). The carbonate pebble content of this drift is relatively high in comparison to that of the younger drifts (Figure 21), but in the southeastern corner of the map-area, high and low values are juxtaposed. In the same area, the ratio of hornblende to garnet in the Wild Horse drift is also very variable (Figure 23). This effect may be the result of two drift sheets (Wild Horse and pre-Wild Horse drifts) expressing themselves. The fresh appearance of the glacial land forms clearly stamp this drift as belonging to the Wisconsin Stage (plates 8 and 12B). Along the preglacial divide that joins the Cypress Hills and Sweet Grass Hills, however, the drift was never thick, and badland erosion (chiefly of the bedrock) has been active for a considerable time, producing the "eroded plains" described in Chapter V. It should be mentioned that only in townships 1 and 2, ranges 4, 5, and 6 were exfoliated erratics observed.

Pakowki drift The broad, well defined Pakowki End Moraine occupies most of the terrain between Etzikom Coulee and the Milk River Valley. Pakowki drift also covers the western and northern outer slopes of the Cypress Hills Upland (Figure 32). It lies mainly on Foremost and Oldman beds, has a loam texture, is slightly coarser-grained than the Wild Horse drift (figures 15 and 18), and contains more Precambrian crystalline pebbles than the older drifts (Figure 21). It is of Wisconsin age.

Etzikom drift and Oldman drift The Etzikom and Oldman drift sheets occupy the northwestern quadrant of the map-area (Figure 32). The former is closely associated in time and space with the Pakowki drift (Figure 30) and the Oldman drift, which just extends into the northwestern corner of the map-area, is probably not much younger than the Etzikom drift. The radiocarbon date of

10,500 ± 200 (GSC-3) -- on willow wood from a small channel that was eroded by Oldman River during early development of its postglacial valley -- gives the minimum age of the Oldman drift.

Manyberries volcanic ash

The Manyberries volcanic ash is exposed just south of Manyberries, at Lsd.14 S.13 Tp.5 R.6 (Plate 29). It is a 6-inch thick bed, pale greyish orange (10YR7/2) in colour, contains few detrital contaminants, and grades from a fine sand at the base to a clay at the top. The ash bed is covered by 20 to 25 feet of lacustrine sand, silt, and clay and is underlain by four feet of lacustrine silt below which occurs one foot of outwash gravel and sand which lies on till. At one place along the section, the dip on the ash bed and adjacent lacustrine sediment suddenly steepens and here the beds are cut by small normal faults (Plate 29). These post-depositional structures indicate that the beds locally collapsed due to the loss of support at depth, which most probably occurred as a result of the disappearance, by melting, of buried blocks of ice.

As pointed out by Powers and Wilcox (1964), layers of volcanic ash are sufficiently common in young deposits of northwestern United States and adjacent Canada to serve as horizon markers in geological and archaeological stratigraphy, provided they can be identified and correlated. The Manyberries volcanic ash was therefore studied in some detail in an attempt to correlate it with radiocarbon-dated ashes nearby (Horberg and Robie, 1955; Powers and Wilcox, 1964).

The Manyberries ash contains 2 per cent fine sand, 93 per cent silt, and 5 per cent clay. The mineralogy, refractive index of the glass, and composition of the plagioclase feldspars are given in Table IX. The refractive index of the glass ($n = 1.500$ to 1.501) is definitely lower than the Galata ash in Montana ($n = 1.510 \pm .005$) which Horberg (1955) thought came from the southwestern Glacier Park area, in Washington. Powers and Wilcox (1964), on chemical and petrographic

MINERAL TYPE 0.125 to 0.062 mm. size fraction	PERCENTAGE FREQUENCY[1]
Glass(with abundant iron oxide)	42
Glass (clear)	29
Feldspar (mainly plagioclase)	19
Quartz	5
Hornblende	3
Magnetite	1
Orthopyroxene	1
Garnet	tr
Calcite	tr
Biotite	tr
Refractive index of glass	1.500 - 1.501
Composition of plagioclase feldspar[2]	Andesine ($Ab_{55}An_{45}$)

TABLE IX. Mineralogy of the Manyberries volcanic ash

[1] 300 grains counted

[2] Calculated from maximum extinction angles of albite twins in sections normal to [010] · $n > 1.54$

evidence, believe the Galata ash came from Mount Mazama, Oregon. They identified two volcanic ash deposits, both widespread throughout northwestern United States and adjacent Canada; one from Mount Mazama, about 6600 radiocarbon years old, and the other from Glacier Peak, in Washington, "perhaps very late glacial or early postglacial in age". The mineralogy of the Manyberries volcanic ash agrees more closely to that of the older Glacier Peak ash -- low refractive index of the glass, and absence of apatite and augite. This correlation is further supported by the collapse structures in the Manyberries ash, which suggest that this ash was deposited whilst ice of Pakowki age still existed (Plate 29).

Forthcoming radiocarbon dates from the Foremost-Cypress Hills area

Three samples have been submitted to the University of Saskatchewan for radiocarbon age determination. No results are available as yet, but the particulars of each sample and the possible significance of the radiocarbon dates are given below.

(1) Stems of Equisetum sp. were collected from deltaic sands at the northeastern corner of Lake Pakowki (Lsd.5 S.16 Tp.5 R.7). The rushes were in their original growth positions and the sample was collected 6 feet below the surface. The radiocarbon age of the rushes will date the deltaic sands and give the minimum age of the Etzikom drift.

(2) Just north of the map-area, along the South Saskatchewan Valley at S.5 Tp.14 R.5, bison bones (Bison occidentalis ?) were found in glacial sands beneath the lowermost till sheet. The radiocarbon age of these bones will date a major glacial advance in southeastern Alberta (see Appendix C for complete description of the section).

(3) Wood, associated with bones of Bison bison bison, was recovered from a river terrace at Lsd.3 S.30 Tp.2 R.3. The terrace is composed of massive and horizontally bedded silt with some sand and pebble horizons. The radiocarbon age

of this wood will give the time of aggradation of the channel, a minimum date for the deglaciation of the area, as well as dating the bison remains.

Radiocarbon dates from adjacent areas and their significance

In the Prelate map-area (72 K), Saskatchewan, immediately to the northeast of the Foremost-Cypress Hills area (72 E), Mr. Peter David identified a palaeosol that has been radiocarbon dated at approximately 20,000 years B.P. (Peter David, 1964, written communication). One major drift sheet underlies this palaeosol and two overlie it. Hence, a major readvance of the Laurentian ice sheet occurred about 20,000 years ago. The ice overrode the whole of the Prelate map-area, passed into the Foremost-Cypress Hills area, and its terminus must be represented by one of the end moraines shown in figures 28 and 32. A younger glacial advance in the northeastern part of the Prelate area has been dated at about 10,250 years B.P. (Peter David, 1964, written communication; S-174).

CHAPTER IX - GLACIAL HISTORY

Frost action structures in the upper part of the Saskatchewan gravels and sands indicate a periglacial climate existed in the map-area just prior to the incursion of the first Laurentian ice sheet.

Phase no. 1

Phase no. 1 of the glacial history commenced with the invasion of the area by the Laurentian glacier that deposited the pre-Wild Horse drift. Whether this was the first glacier to enter the map-area is not known for there may have been older, less extensive glaciers. This glacier reached an elevation of 4500 feet above sea level on the northern slopes of the Cypress Hills, which formed a nunatak about 300 feet high. Deformation of the Cypress Hills conglomerate by frost action and deposition of the Cypress Hills loess occurred at this time. To the south, the Sweet Grass Hills stood as giant nunataks, extending 2000 feet above the glacier's surface. These upland areas must have exerted a pronounced influence on the direction of ice movement, which was most probably towards the south in the western part of the map-area, and towards the southeast in the southeastern part of the map-area (Figure 33). This glacier penetrated into Montana and the most southerly position it reached is represented by the outer limit of glaciated terrain (figures 28 and 30).

Phase no. 2

During this phase the glacier most probably retreated out of the map-area. The large re-entrants along the ice margin of the next glacier that moved into the map-area and Montana (Figure 28) show that the earlier glacier certainly retreated north of the 49th Parallel. During ablation of this earlier glacier, meltwater channels were formed around the Cypress Hills, the meltwater being conducted to the east

and southeast. Elsewhere, the character of the drift and glacial land forms that were produced at this time, have largely been destroyed by later ice advances.

Phase no. 3

A major readvance of the Laurentian ice sheet occurred at this time. This glacier, which deposited the Wild Horse drift, reached an elevation of 4100 feet on the northern slopes of the Cypress Hills. At this time, some meltwater probably flowed to the east and southeast along channels around the Cypress Hills into Saskatchewan. The glacier flowed towards the south in the western half of the map-area, but, between the Cypress Hills and Sweet Grass Hills, was forced to flow towards the southeast (Figure 34). Figure 28 shows that this glacier was split into two lobes by the Sweet Grass Hills: the western ice lobe moved southwards into Montana whereas the larger eastern lobe flowed southeastwards into Montana.

Phase no. 4

The extent of retreat of the glacier that deposited the Wild Horse drift is not known, but the direction of retreat is well recorded by numerous ice-marginal channels and glacial lineaments (Figure 35). In the Cypress Hills area, the glacier receded downslope, and, in the process, successively lower ice-marginal channels were formed which conducted meltwater to the east and southeast. At the same time, the glacier retreated down the northern slope of the Sweet Grass Hills, where initially the meltwater drained to the south along consequent meltwater channels (Coutts, Clarinda, Pinhorn channels; Figure 32), but later flowed eastwards and southeastwards along the Milk River Ice-marginal Channel.

Southeast of the preglacial divide that joins the Cypress Hills and the Sweet Grass Hills (Map 8), the glacier became stagnant. Meltwater was conducted southeastwards along subglacial tunnels in which eskers formed. When this stagnant ice became thin, the esker ridges emerged above its surface, impeded the flow of

superglacial meltwater which resulted in the formation of Superglacial Lake Wild Horse (plates 14B and 19).

Retreat of the glacier northwest of the Ancestral Milk River Valley must have led to the formation of a proglacial lake near the present site of Lake Pakowki. During the early stages of this lake, its waters most probably drained southeastwards along Canal Channel (Figure 32) which became a subglacial tunnel in the southeastern corner of the map-area (Figure 35). Lost River Channel most probably drained water from this lake at a later date.

During the recession of the glacier (that deposited the Wild Horse drift) from Montana and the map-area, minor readvances occurred. The lobate end moraine near Wild Horse was deposited during one of these minor readvances.

Phase no. 5

Phase no. 5 of the glacial history in the Foremost-Cypress Hills area is marked by another major readvance of the Laurentian ice sheet. This glacier, which deposited the Pakowki drift, reached an elevation of about 3200 feet. It surrounded the Cypress Hills Upland, and nosed southeastwards across the depression now occupied by Lake Pakowki, but did not overtop the preglacial divide. To the west, this glacier did not cover the Lucky Strike Upland. At this time, meltwater again flowed along Milk River and Lost River channels (Figure 36).

Phase no. 6

As the ice front receded downslope, Glacial Lake Pakowki formed between it and the preglacial divide that joins the Cypress and Sweet Grass Hills. Meltwater drained through successively lower outlets as frontal retreat of the glacier continued. Initially, Glacial Lake Pakowki drained southeastwards via Lost River Channel (about 2950 feet above sea level). With further backwasting of the ice front, the glacial waters found a lower outlet, the Pakowki Channel

(less than 2900 feet above sea level), which conducted meltwater into Milk River Channel. Later, Etzikom Ice-marginal Channel contributed a considerable volume of meltwater to Glacial Lake Pakowki, whose waters drained via Pakowki Channel to Milk River Channel. Milk River Canyon was formed at this time.

The extent of retreat of this glacier is not known, but the now buried Granlea Channel (township 8, range 9; Map 1), north of Lake Pakowki, may mark the ice-frontal position at the time of maximum retreat. The position of this channel to the west and east of Granlea is not precisely known, but it probably closely followed the present Chin and Seven Persons channels. The Manyberries volcanic ash was deposited during phase no. 6.

Phase no. 7

During this phase the Laurentian ice sheet readvanced to the south and nosed southeastwards across the northern part of Glacial Lake Pakowki. It buried Granlea Channel as well as part of Etzikom Channel, and reached an elevation of about 3000 feet. Meltwater flowed eastwards along Etzikom Ice-marginal Channel, debouched into Glacial Lake Pakowki and from here flowed through Pakowki Channel to Milk River Canyon (Figure 38).

Phase no. 8

The direction of retreat of the glacier that deposited the Etzikom drift is well recorded by numerous ice-marginal channels and glacial lineaments (Figure 39). Initially, meltwater flowed along the same path described in phase no. 7. Contemporaneously, north of the Cypress Hills, meltwater drained to the northeast along the Norton Channel (Figure 32). As the glacier retreated downslope, successively lower ice-marginal channels were formed. When the Chin - Seven Persons - Irvine channel system was formed, all meltwater drained to the east and northeast. Continued backwasting of the glacier to the north and northwest

resulted in the formation of Glacial Lake Medicine Hat (township 12, ranges 5 and 6), which overlies the Ancestral Milk River Valley, and Forty Mile Channel, which conducted meltwater southeastwards into the Seven Persons Channel. North of the Chin Ice-marginal Channel, meltwater from an ablating ice lobe was conducted eastwards to Forty Mile Channel along numerous small ice-marginal channels (Plate 20). This glacier most probably retreated out of the map-area.

Phase no. 9

Phase no. 9 of the glacial history is marked by another readvance of the Laurentian ice sheet. The glacier moved into the northwestern part of the map-area flowing to the south and southeast (Figure 40). It deposited the Oldman drift and reached an elevation of about 2600 feet. This was the last glacier to move into the map-area.

Phase no. 10

During this phase meltwater was ponded in front of the glacier, forming a shallow proglacial lake. Later, after the glacier had retreated a short distance to the north, meltwater drained eastwards along the Oldman and South Saskatchewan ice-marginal channels. The South Saskatchewan Canyon was formed at this time (Map 1).

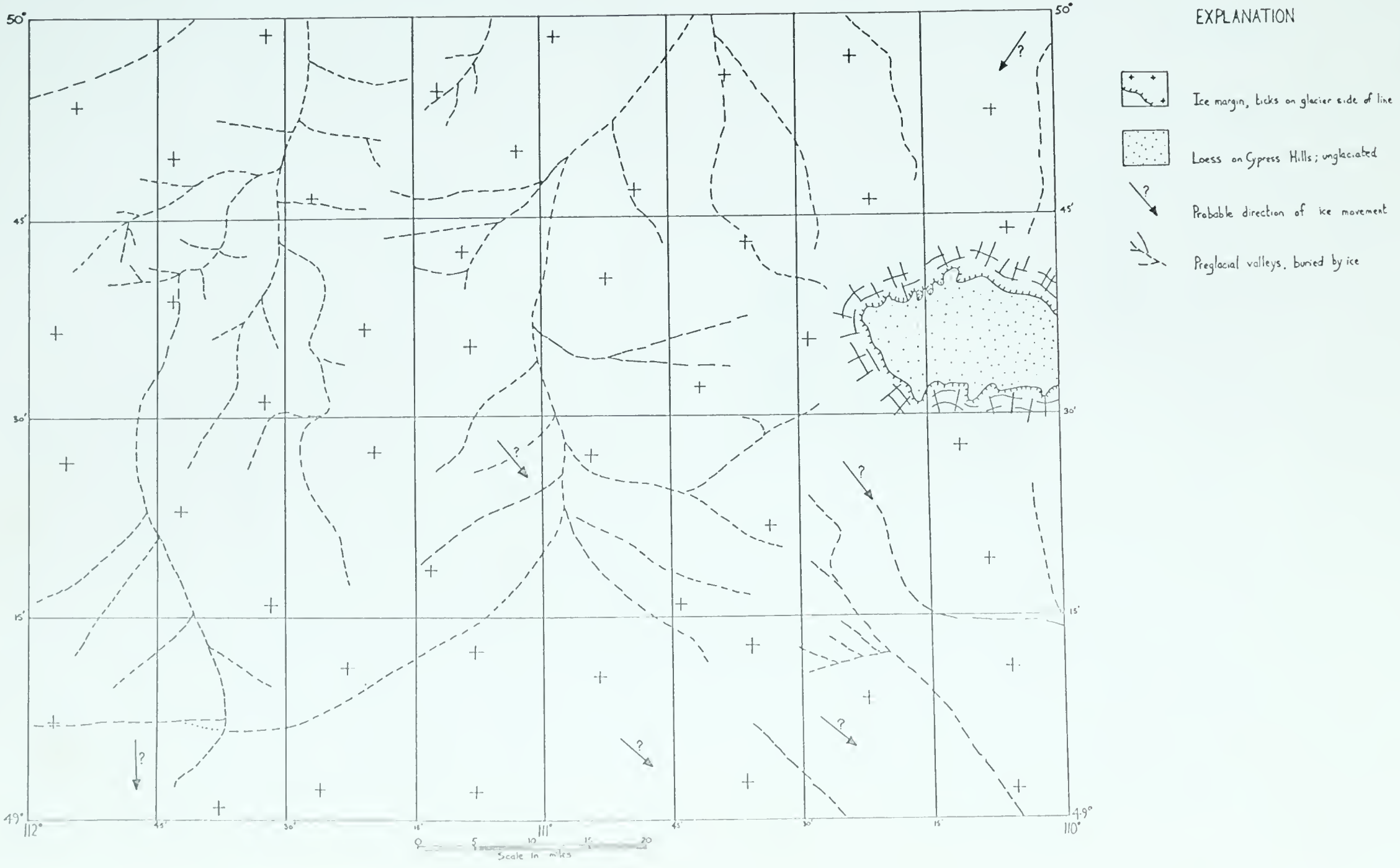


Figure 33. Phase no. 1 of glacial history

Figure 34. Phase no. 3 of glacial history

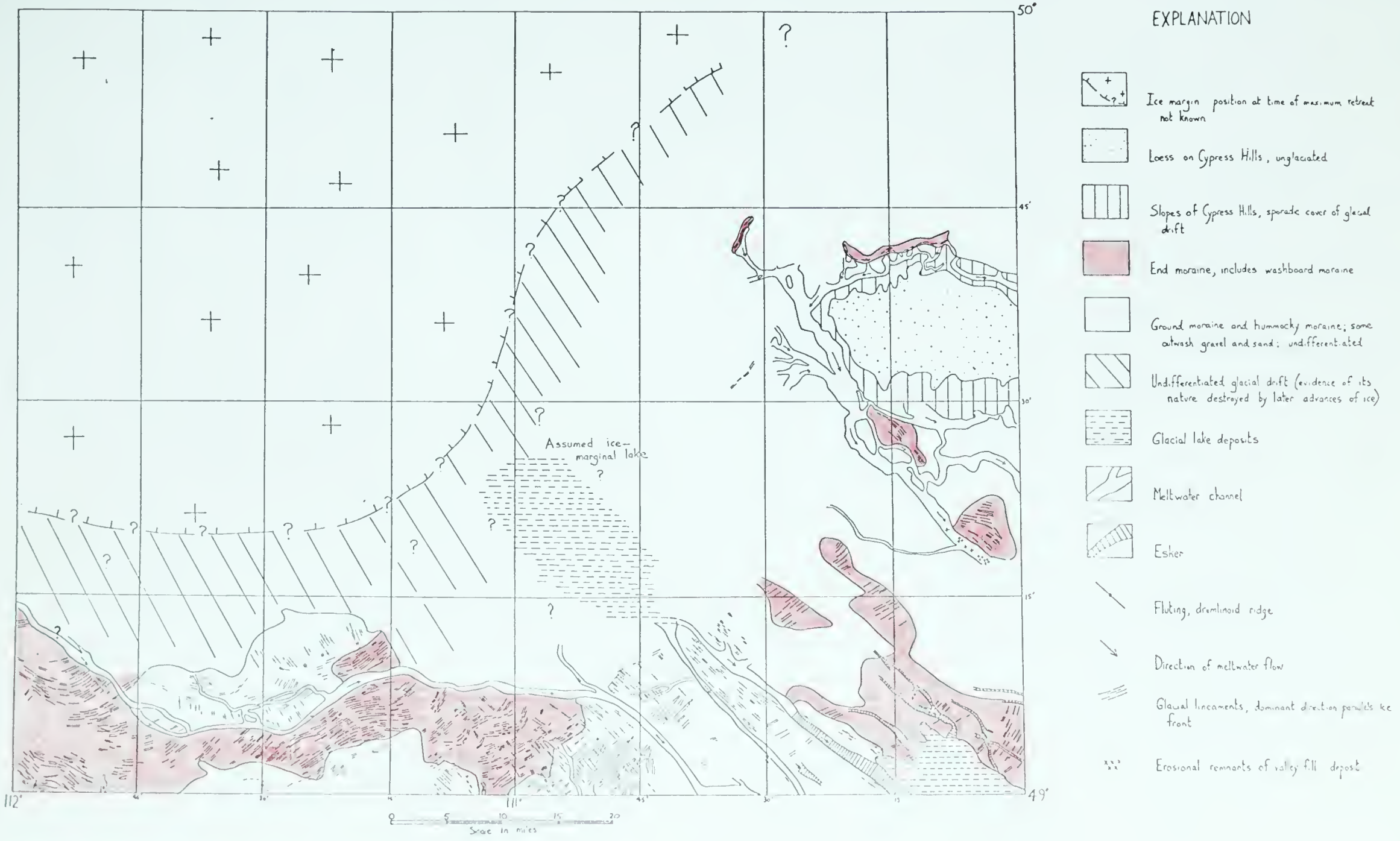
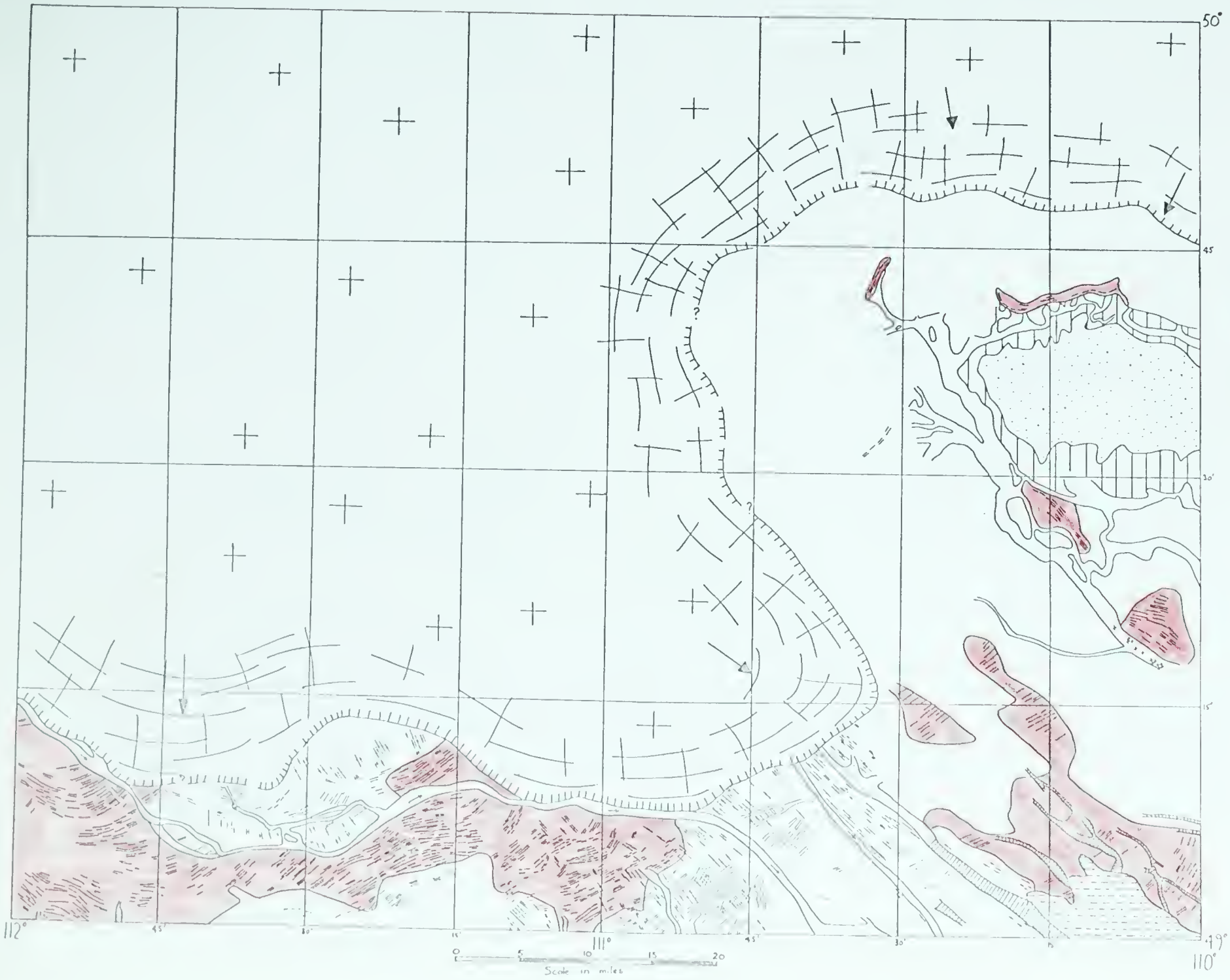


Figure 35. Phase no. 4 of glacial history



EXPLANATION

- Ice margin
- Loess on Cypress Hills; unglaciated
- Slopes of Cypress Hills, sporadic cover of glacial drift
- End moraine, includes washboard moraine
- Ground moraine and hummocky moraine, some outwash gravel and sand, undifferentiated
- Glacial lake deposits
- Meltwater channel
- Esker
- Fluting, drumlinoid ridge
- Direction of ice movement
- Direction of meltwater flow
- Glacial lineaments, dominant direction parallels ice front
- Erosional remnants of valley fill deposit

Figure 36. Phase no. 5 of glacial history

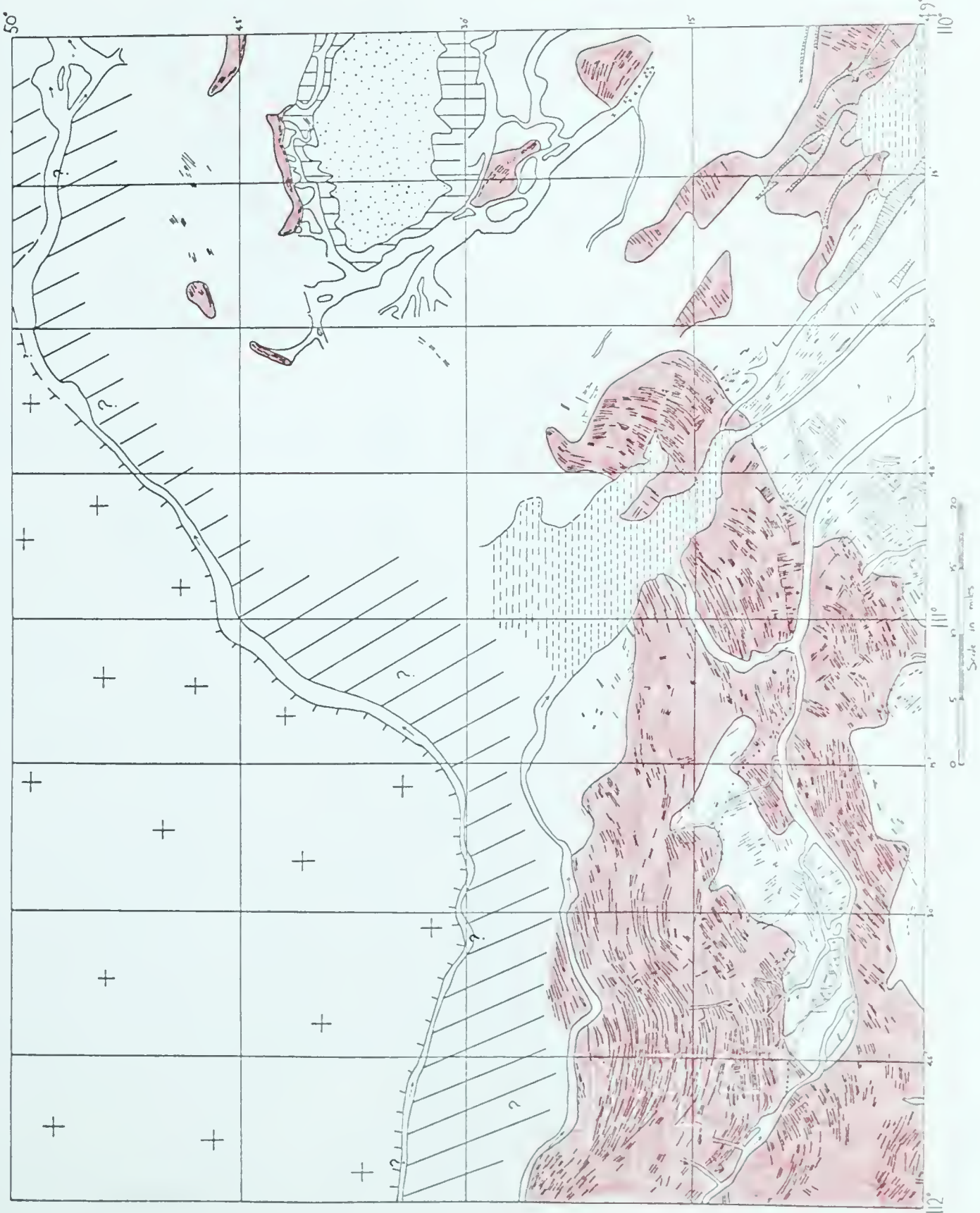


Figure 37. Phase no. 6 of glacial history

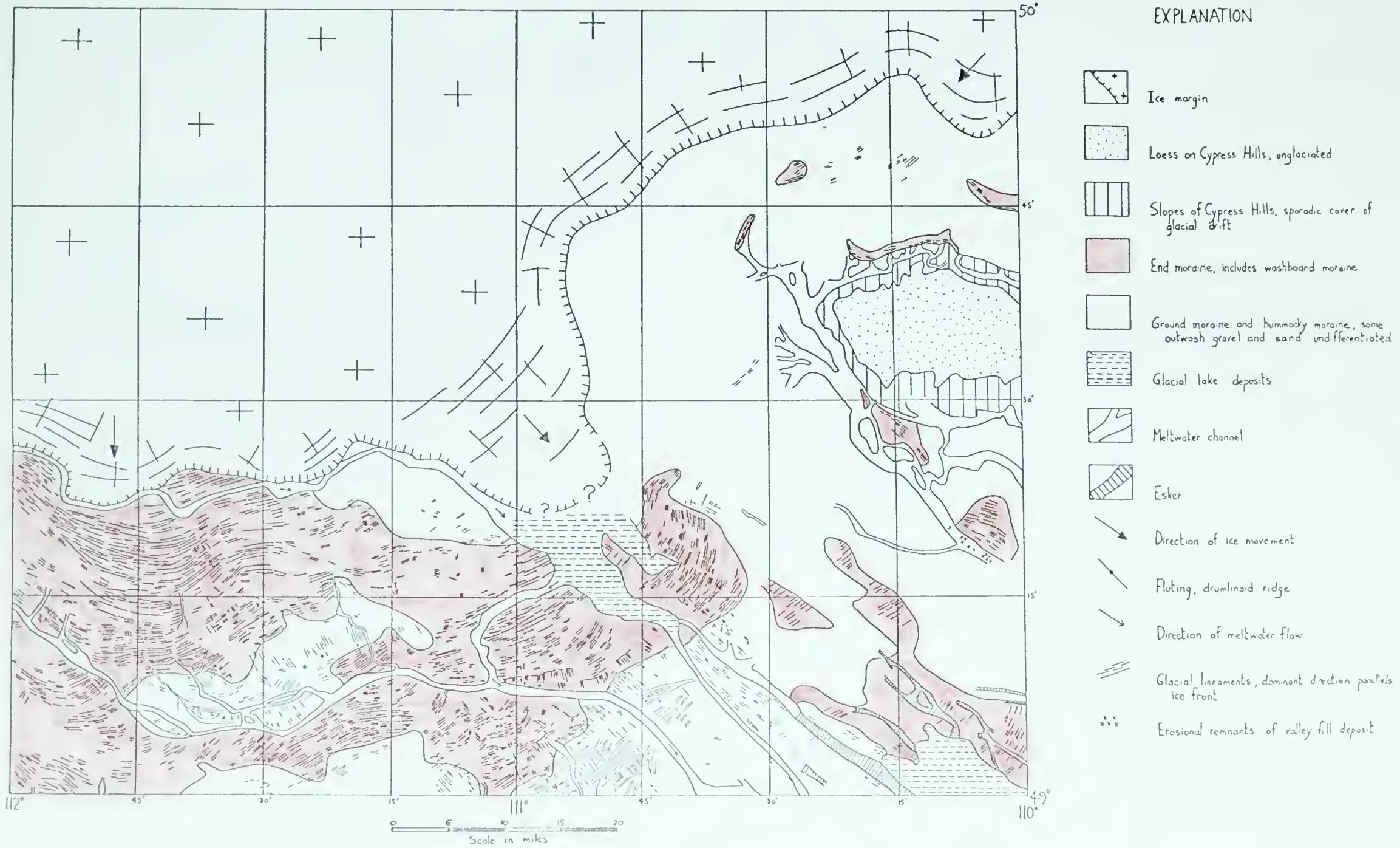


Figure 38. Phase no. 7 of glacial history

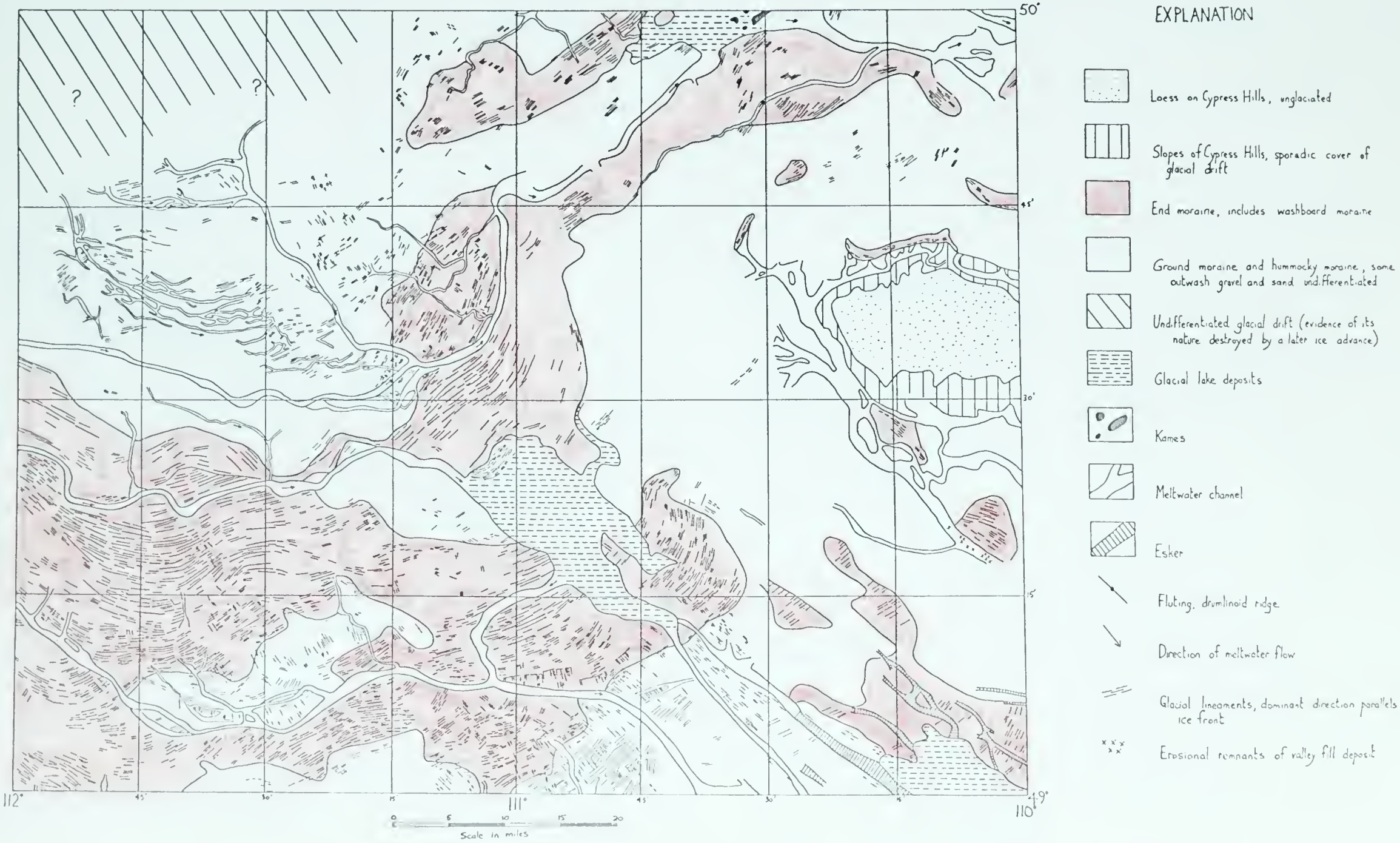


Figure 39. Phase no. 8 of glacial history

Figure 40. Phase no. 9 of glacial history

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APPENDIX A

LOCATION OF SAMPLES

Sample number	Description	Location
161	Bearpaw shale	Lsd. 5 S.25 Tp.6 R.3 W.4
561	Till	Lsd.12 S.28 Tp.6 R.4 W.4
661	Pebble count from till	"
861	Till	Lsd.11 S.28 Tp.7 R.4 W.4
961	Till	Lsd. 4 S. 3 Tp.8 R.4 W.4
1061	Cypress Hills loess	Lsd.13 S.14 Tp.7 R.1 W.4
1261	Cypress Hills loess	Lsd. 7 S.25 Tp.7 R.2 W.4
1361	Till	Lsd.16 S.33 Tp.6 R.2 W.4
1461	Cypress Hills loess	Lsd. 4 S.28 Tp.7 R.1 W.4
1661	Cypress Hills loess	Lsd.12 S.34 Tp.7 R.2 W.4
1761	Cypress Hills loess	Lsd. 5 S.15 Tp.7 R.3 W.4
2061	Eastend sandstone	Lsd. 4 S.20 Tp.8 R.3 W.4
2261	Till	Lsd. 8 S.35 Tp.8 R.3 W.4
2361	Till	Lsd.13 S. 8 Tp.9 R.3 W.4
2461	Pebble count from till	"
2561	Cypress Hills loess	Lsd.12 S. 9 Tp.8 R.3 W.4
2661	Cypress Hills conglomerate	Lsd.11 S.10 Tp.8 R.3 W.4
2761	Cypress Hills loess	"
2861	Till	Lsd.13 S.27 Tp.8 R.4 W.4
2961	Pebble count from till	"
3061	Ravenscrag ? sandstone	Lsd. 4 S.20 Tp.8 R.3 W.4
3261	Fossiliferous lacustrine sediment	Lsd.13 S.28 Tp.8 R.4 W.4
3361	Till	Lsd.12 S.31 Tp.8 R.2 W.4
3461	Till	Lsd.10 S.29 Tp.8 R.3 W.4
3561	Pebble count from till	"
3661	Till	Lsd. 3 S.21 Tp.8 R.4 W.4
3761	Pebble count from till	"
3861	Till	Lsd. 5 S. 1 Tp.9 R.3 W.4
3961	Pebble count from till	"
4461	Cypress Hills conglomerate	Lsd. 5 S.17 Tp.8 R.2 W.4
4561	Cypress Hills loess	Lsd. 8 S.25 Tp.8 R.2 W.4
4661	Till	Lsd. 4 S. 3 Tp.9 R.2 W.4
4761	Pebble count from till	Lsd. 4 S. 3 Tp.9 R.2 W.4
4961	Fossiliferous lacustrine sediment	Lsd. 6 S.23 Tp.9 R.1 W.4
5061	Fossiliferous lacustrine sediment	"
5361	Till	"
5461	Till	"
5561	Pebble count from till	"
5661	Till	Lsd.16 S.13 Tp.9 R.1 W.4
5761	Till	Lsd. 8 S.25 Tp.8 R.1 W.4
5861	Till	"
5961	Pebble count from till	"
6061	Till	Lsd.16 S.27 Tp.8 R.1 W.4
6161	Pebble count from till	"

Sample number	Description	Location
6261	Till	Lsd.13 S.11 Tp.9 R.1 W.4
6361	Till	"
6461	Till	Lsd. 1 S. 8 Tp.9 R.1 W.4
6561	Pebble count from till	Lsd. 8 S. 1 Tp.9 R.2 W.4
6661	Pebble count from till	Lsd. 3 S.32 Tp.8 R.2 W.4
6861	Till	Lsd.11 S.27 Tp.9 R.4 W.4
6961	Till	Lsd. 4 S.25 Tp.9 R.3 W.4
7061	Pebble count from till	"
7161	Pebble count from till	"
7361	Till	Lsd. 4 S. 3 Tp.10 R.4 W.4
7461	Pebble count from till	"
7561	Till	Lsd.16 S.22 Tp.9 R.4 W.4
7661	Pebble count from till	"
7761	Pebble count from till	Lsd.11 S.3 Tp.10 R.3 W.4
7861	Till	Lsd.13 S.33 Tp.9 R.1 W.4
7961	Till	Lsd.10 S.1 Tp.10 R.1 W.4
8061	Pebble count from till	"
8161	Till	"
8261	Pebble count from till	"
8461	Fossiliferous silts from terrace	Lsd.13 S.14 Tp.10 R.1 W.4
8561	Till	Lsd. 3 S. 1 Tp.10 R.1 W.4
8661	Pebble count from till	"
8861	Till	Lsd.12 S.28 Tp.9 R.2 W.4
8961	Pebble count from till	"
9061	Till	Lsd.13 S.31 Tp.9 R.1 W.4
9161	Till	Lsd. 9 S.24 Tp.9 R.2 W.4
9261	Till	Lsd. 9 S.36 Tp.9 R.1 W.4
9361	Till	Lsd. 7 S.29 Tp.9 R.1 W.4
9461	Pebble count from till	"
9561	Till	"
9661	Pebble count from till	"
9761	Pebble count from till	Lsd.12 S.34 Tp.9 R.1 W.4
9861	Fossiliferous silts from terrace	Lsd.13 S.14 Tp.10 R.1 W.4
10061	Fossiliferous lacustrine sediment	Lsd. 2, S.30 Tp.9 R.2 W.4
1762	Pebble count from till	Lsd. 3 S.20 Tp.4 R.2 W.4
1862	Till	"
2062	Pebble count from till	Lsd. 1 S.34 Tp.4 R.3 W.4
2162	Pebble count from till	Lsd. 8 S.35 Tp.4 R.4 W.4
2262	Till	"
2462	Cypress Hills loess	Lsd.11 S.10 Tp.8 R.3 W.4
2562	Cypress Hills loess	"
2662	Till	Lsd.10 S.10 Tp.6 R.1 W.4
2762	Pebble count from till	Lsd.14 S.34 Tp.5 R.1 W.4
2862	Till	Lsd. 6 S.12 Tp.4 R.1 W.4
2962	Pebble count from till	"
3062	Pebble count from till	Lsd.13 S.34 Tp.9 R.1 W.4
3162	Pebble count from till	"
3262	Pebble count from till	"
3362	Pebble count from till	"
3762	Till	Lsd.13 S.14 Tp.9 R.3 W.4

Sample number	Description	Location
4262	Fossiliferous lacustrine silt	Lsd. 2 S.18 Tp.10 R.5 W.4
4362	Fossiliferous lacustrine silt	"
4662	Till	Lsd.15 S.31 Tp. 9 R.5 W.4
4762	Pebble count from till	"
4862	Pebble count from till	"
4962	Pebble count from till	Lsd. 4 S.30 Tp. 9 R.4 W.4
5062	Till	"
5262	Pebble count from till	Lsd.11 S.30 Tp. 9 R.6 W.4
5362	Till	"
5462	Pebble count from till	Lsd. 2 S.35 Tp. 9 R.7 W.4
5562	Pebble count from till	Lsd. 4 S. 3 Tp. 9 R.7 W.4
5662	Till	"
5762	Pebble count from till	Lsd. 4 S.30 Tp. 7 R.7 W.4
5862	Till	Lsd. 4 S.30 Tp. 7 R.7 W.4
5962	Pebble count from till	Lsd. 8 S.16 Tp. 7 R.7 W.4
6062	Pebble count from till	Lsd. 1 S.36 Tp. 7 R.7 W.4
6162	Pebble count from till	Lsd.13 S.34 Tp. 8 R.6 W.4
6362	Pebble count from till	Lsd.13 S.32 Tp. 8 R.5 W.4
6462	Pebble count from till	Lsd. 3 S.30 Tp. 7 R.4 W.4
6662	Pebble count from till	Lsd. 9 S.10 Tp. 5 R.6 W.4
6762	Till	"
7162	Pebble count from till	Lsd.13 S.34 Tp. 5 R.7 W.4
7562	Pebble count from till	Lsd.15 S.15 Tp. 4 R.8 W.4
7662	Pebble count from till	Lsd.15 S. 4 Tp. 6 R.5 W.4
7762	Pebble count from till	Lsd.14 S.11 Tp. 6 R.6 W.4
7862	Pebble count from till	Lsd. 9 S.15 Tp. 5 R.5 W.4
7962	Till	Lsd. 1 S.29 Tp. 4 R.5 W.4
8062	Pebble count from till	"
8162	Manyberries volcanic ash	Lsd.14 S.13 Tp. 5 R.6 W.4
8562	Cypress Hills loess	Lsd.13 S.21 Tp. 8 R.1 W.4
8862	Frenchman sandstone	Lsd.16 S. 9 Tp. 8 R.4 W.4
9162	Oldman sandstone	Lsd. 9 S.10 Tp. 5 R.6 W.4
9962	Till and pebble count	Lsd. 7 S.17 Tp.11 R.5 W.4
10062	Till and pebble count	Lsd.15 S.31 Tp. 9 R.5 W.4
10162	Till and pebble count	"
10262	Till and pebble count	NW 1/4 S.32 Tp.8 R.5 W.4
10362	Till and pebble count	SW 1/4 S.10 Tp.8 R.5 W.4
10462	Till and pebble count	SW 1/4 S.31 Tp.7 R.6 W.4
10562	Till and pebble count	NW 1/4 S.19 Tp.8 R.6 W.4
10662	Till and pebble count	SE 1/4 S.17 Tp.6 R.7 W.4
10762	Till and pebble count	SW 1/4 S.13 Tp.6 R.8 W.4
10862	Till and pebble count	SE 1/4 S.15 Tp.6 R.6 W.4
11062	Till and pebble count	NE 1/4 S.20 Tp.2 R.7 W.4
11362	Till and pebble count	NW 1/4 S.17 Tp.3 R.2 W.4
11462	Till and pebble count	SW 1/4 S.13 Tp.5 R.3 W.4
11562	Till and pebble count	SW 1/4 S. 3 Tp.10 R.3 W.4
263	Skull of *Bison bison bison*	Lsd2,3 S.30 Tp. 2 R.3 W.4
363	Fossiliferous sands and clays	Lsd. 2 S.34 Tp. 2 R.7 W.4
663	Till and pebble count	Lsd.13 S.33 Tp. 2 R.5 W.4

Sample number	Description	Location
863(i)	Till and pebble count	Lsd.13 S. 4 Tp. 1 R.5 W.4
863(ii)	Till and pebble count	Lsd.13 S. 4 Tp. 1 R.5 W.4
963	Till and pebble count	Lsd. 6 S.14 Tp. 1 R.5 W.4
1063	Till and pebble count	Lsd. 2 S.21 Tp. 2 R.5 W.4
1163	Till and pebble count	Lsd.16 S.31 Tp. 2 R.5 W.4
1262	Till and pebble count	Lsd. 1 S. 5 Tp. 2 R.7 W.4
1363	Till and pebble count	Lsd.12 S.11 Tp. 3 R.4 W.4
1463	Till and pebble count	Lsd. 1 S.12 Tp. 3 R.4 W.4
1563	Till and pebble count	Lsd.11 S.25 Tp. 3 R.4 W.4
1763	Till and pebble count	Lsd.13 S. 2 Tp. 2 R.4 W.4
1863	Till and pebble count	Lsd. 9 S. 1 Tp. 1 R.4 W.4
1963	Till and pebble count	Lsd.13 S.22 Tp. 1 R.3 W.4
2163	Till and pebble count	Lsd.14 S.14 Tp. 2 R.3 W.4
2263	Till and pebble count	Lsd.16 S.30 Tp. 3 R.2 W.4
2363	Till and pebble count	Lsd. 4 S.31 Tp. 2 R.2 W.4
2463	Till and pebble count	Lsd. 1 S. 7 Tp. 2 R.1 W.4
2563	Till and pebble count	Lsd. 2 S.19 Tp. 2 R.1 W.4
2663	Till and pebble count	Lsd.14 S.10 Tp. 3 R.2 W.4
2763	Till and pebble count	Lsd. 5 S.30 Tp. 3 R.1 W.4
2863	Till and pebble count	Lsd. 6 S. 6 Tp. 3 R.1 W.4
2963	Till and pebble count	Lsd. 3 S.24 Tp. 3 R.1 W.4
3063	Till and pebble count	Lsd. 8 S.10 Tp. 2 R.5 W.4
3163	Till and pebble count	Lsd.12 S. 2 Tp.12 R.1 W.4
3263	Till and pebble count	Lsd. 4 S.17 Tp.11 R.2 W.4
3363	Till and pebble count	Lsd.12 S. 2 Tp.11 R.2 W.4
3463	Till and pebble count	Lsd. 5 S.35 Tp.10 R.1 W.4
3563(i)	Till and pebble count	Lsd.14 S.36 Tp.10 R.1 W.4
3563(ii)	Till and pebble count	"
3663	Fossiliferous lacustrine sediment	Lsd.10 S.18 Tp.10 R.2 W.4
3763	Till and pebble count	Lsd. 5 S.23 Tp.11 R.3 W.4
3863	Till and pebble count	Lsd.10 S.18 Tp.11 R.3 W.4
3963(i)	Till and pebble count	Lsd. 2 S.14 Tp.11 R.4 W.4
3963(ii)	Till and pebble count	"
4163(i)	Till and pebble count	Lsd. 6 S. 4 Tp.11 R.5 W.4
4163(ii)	Till and pebble count	"
4263	Till and pebble count	Lsd. 1 S.1 Tp.12 R.11 W.4
4363	Till and pebble count	Lsd.1 S.10 Tp.12 R.11 W.4
4463	Saskatchewan gravels and sands	Lsd.6 S.23 Tp.11 R.15 W.4
4563	Till and pebble count	Lsd. 4 S.16 Tp. 8 R.8 W.4
4663(i)	Till and pebble count	Lsd. 4 S.22 Tp.7 R.10 W.4
4663(ii)	Till and pebble count	"
4763	Till and pebble count	Lsd. 2 S. 2 Tp.5 R.13 W.4
4863	Till and pebble count	Lsd. 3 S.10 Tp.2 R.10 W.4
4963	Till and pebble count	Lsd. 6 S.13 Tp. 3 R.9 W.4
5163	Till and pebble count	Lsd. 4 S.15 Tp.1 R.12 W.4

APPENDIX B

CALCITE-DOLOMITE CONTENT OF TILL

The standard curves, which were used to determine the amount of calcite and dolomite in till, are given in Figure 41. A Chittick gasometric apparatus was used. All samples weighed 1.700 gm. and were finer than 200-mesh. The detailed procedure is given by Dreimanis (1962).

The dolomite sample (a pebble) was obtained from till just north of the Cypress Hills. It was analysed by John Jansen, Dept. Geology, University of Alberta: $CaCO_3$ = 55.7%; $MgCO_3$ = 42.65%.

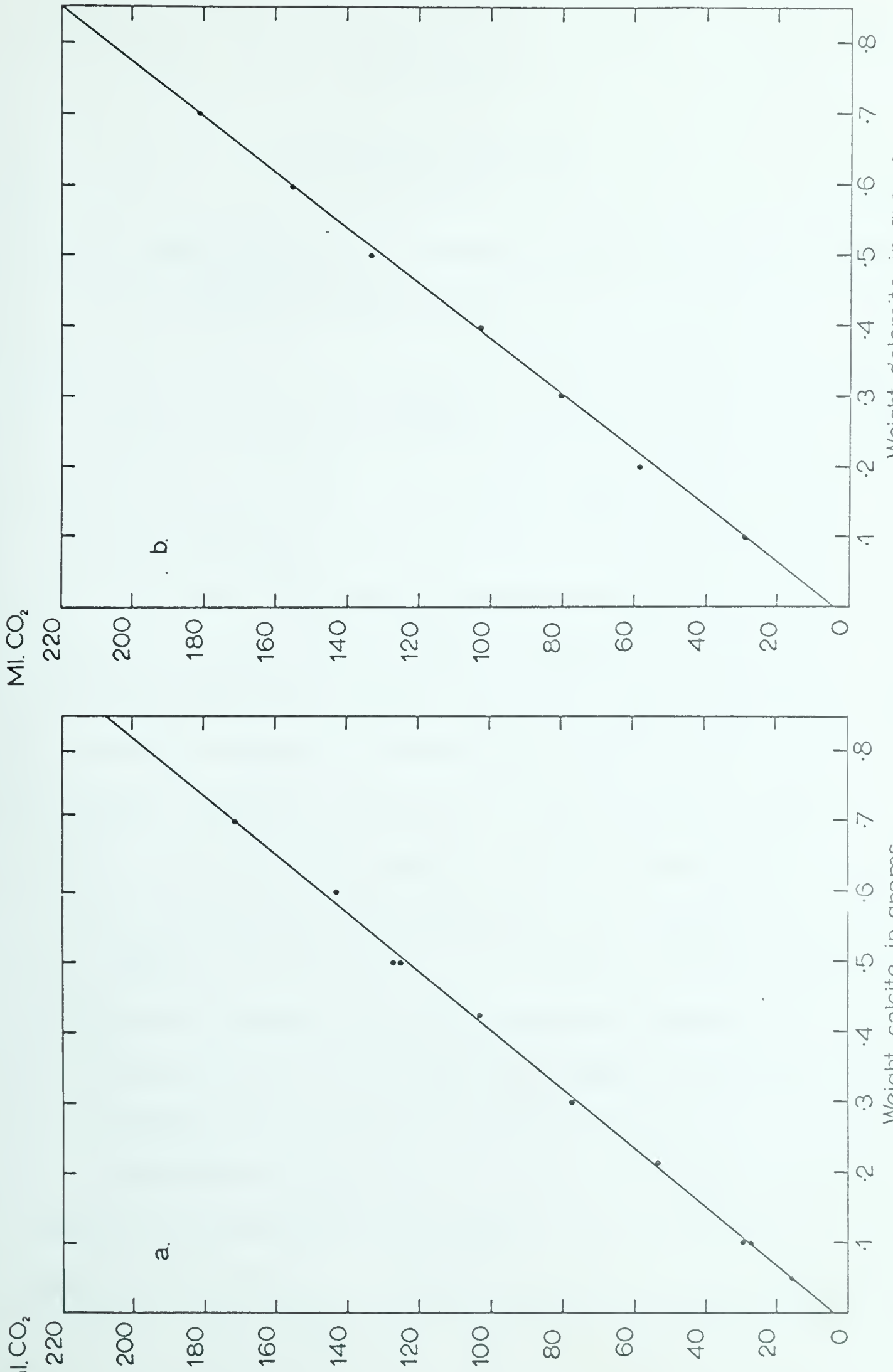


Figure 41. (a) Weight calcite (gms.) versus CO_2 evolved when reacting with hydrochloric acid. All results have been corrected for temperature and barometric pressure.

(b) Weight dolomite (gms.) versus CO_2 evolved when reacting with hydrochloric acid. All results have been corrected for temperature and barometric pressure.

APPENDIX C

PLEISTOCENE SECTIONS

Section 1: Wolf Island Section. North bank of Oldman River, north of Wolf Island, at Lsd.12 S.20 Tp.11 R.14 W.4.

Deposit	Thickness (feet)
Sand and silt, rusty yellow, stones present in upper part	30
Till, dark greyish brown	5
Till, buff to light brown, unconsolidated; exposure poor	80
Bedrock masses, grey bentonitic shale (Cretaceous)	5
Till, dark greyish brown, compact	35
Interbedded till and sand	10
Till, grey, compact	5
Sand, well-sorted, glacial; upper part slightly contorted	15
Clay and silt, dark brown, some beds pink; varved, upper part contorted	10
Saskatchewan gravels and sands; lower part gravel composed dominantly of brown and red quartzites, upper part sand with thin gravel beds; frost action structures in upper part; Canadian Shield stones absent	15
Bedrock, Foremost formation (Cretaceous)	15+

Section 2: Gros Ventre Creek Section. North bank of Gros Ventre Creek, at Lsd.2 S.14 Tp.11 R.4 W.4.

Deposit		Thickness (feet)
Till, buff to light brown, stony; interbedded with few thin silt and sand beds		12.0
Interbedded till and glaciofluvial material:		
Sand, horizontally bedded	1.5	
Till, brown, compact	3.0	
Sand and silt, horizontally bedded	1.8	
Till, grey to buff	0.9	
Clay	0.1	
Sand and silt	1.0	
Gravel	0.2	
Silt	0.7	
Till, grey, compact	0.5	
Sand with lens-shaped inclusions of till; contorted	9.0	18.7
Till, dark grey, compact		4.5
Bedrock, Bearpaw formation (Cretaceous)		10.0+

Section 3: Bullshead Creek Section. Composite section of exposures along east and west banks of Bullshead Creek, at Lsd.15,16 S.31 Tp.9 R.5 W.4.

Deposit	Thickness (feet)
Till, brown, stony; good columnar jointing	30
Till, grey; good columnar jointing	30
Sand, cross-bedded; slightly deformed	3

Silt, yellow to ochre, bedded; slightly deformed	15
Interbedded silt and clay; deformed, (Plate 28 C)	12
Bedrock, Bearpaw formation (Cretaceous)	2+

Section 4: Ross Creek Section 1. East bank of Ross Creek, at Lsd.13 S.18 Tp.10 R.2 W.4

Deposit	Thickness (feet)
Sand, silt and clay	2
Till, buff to light brown; contains flame-shaped inclusions of lower dark till (Plate 30 C)	35
Till, dark greyish brown, compact; contains lens of nonglacial gravel near base	20
Bedrock, Bearpaw formation	50+

Section 5: Mackay Creek Section 1. East bank of Mackay Creek, at Lsd.10 S.1 Tp.10 R.1 W.4

Deposit	Thickness (feet)
Till, light brown	20
Till, light brown; contains numerous flame-shaped inclusions of dark brown till; in places capped by outwash sand	40
Till, dark brown	15+

Section 6: Mackay Creek Section 2. West bank of Mackay Creek, at Lsd.6 S.23 Tp.9 R.1 W.4

Deposit	Thickness (feet)
Till, light brown; (to south grades laterally into fossiliferous lacustrine sand, silt, clay and marl)	4
Outwash sand and fine gravel	13
Till, dark-brown, compact	9
Fine sand, silt and clay with occasional pebbles; upper part deformed	15+

Section 7: Canal Creek Section. Northeast bank of Canal Creek at Lsd.16 S.31 Tp.2 R.5 W.4

Deposit	Thickness (feet)
Silt; a few pebbles present	7
Gravel and sand, glacial	2
Till, compact	5
Sand, minor till inclusions	4
Till, minor sand inclusions	15+

Section 8: Milk River Section. North bank of Milk River, at Lsd.13 S.4 Tp.1 R.5 W.4

Deposit	Thickness (feet)
Sand, minor gravel, inclusions of till; deformed	6
Till, dark brown; iron oxide conspicuous along joints	7-15
Bedrock, Oldman formation (Cretaceous)	4+

Section 9: Ross Creek Section 2. West Bank of Ross Creek, at Lsd.5 S.23 Tp.11 R.3 W.4.

Deposit	Thickness (feet)
Till; buff to light brown, stony, massive	20
Till, greyish buff, interbedded with thin sand beds	20
Till, greyish brown, compact, stony, massive	15+

This section is illustrated on Plate 28, D. Compare with Section 2, the Gros Ventre Creek Section.

Section 10: South Saskatchewan River Section 1. North bank of South Saskatchewan River at NE 1/4 S.9 Tp.13 R.5 W.4.

Deposit	Thickness (feet)
Till, dark greyish brown	20
Sand and silt, yellow	40
Gravel, glacial	1
Till, grey	5
Clay, grey	2
Silt, some sand	40
Saskatchewan gravels and sands; mainly sand, large-scale festoon bedding; contains partly carbonised twigs with a radiocarbon age $29,200 \pm \frac{8100}{4000}$ years B.P. (GX-0102)	30+

Section 11: South Saskatchewan River Section 2. East bank of South Saskatchewan River at NE 1/4 S.4 Tp.13 R.5 W.4.

Deposit	Thickness (feet)
Sand and silt, lacustrine	3
Till, light brown, massive	10
Till, dark brown, massive	15
Silt, some sand, bedded	4
Interbedded till and sand	10
Till, light brown to grey, massive; may consist of two till sheets; in places covered by colluvium; wood fragments from a peat-like horizon in this unit have a radiocarbon age 24,490 ± 200 years B.P. (G.S.C.-205, Stalker, written communication, 1964)	50+

Section 12: South Saskatchewan River Section 3. West bank of South Saskatchewan River at SW 1/4 S.17 Tp.13 R.5 W.4.

Deposit	Thickness (feet)
Sand and silt	10
Gravel, bouldery in places, glacial	1
Sand, cross-bedded, glacial	30
Interbedded gravel and sand; the following fossils have been recovered: a) Camelid, about the size of the modern camel; fragmentary lower part of left scapula b) *Equus* sp., about the size of *E. caballus*; fragment from skull c) *Mammuthus primigenius*, fragments of molar	15

Silt, yellow, preglacial?	3
Saskatchewan gravels and sands; mainly gravel; an incomplete, moderately worn premolar of Mammuthus primigenius recovered; right astragalus of Equus sp., about 10% smaller than E. caballus	10
Bedrock, Foremost formation (Cretaceous)	5+

Section 13: South Saskatchewan River Section 4. East bank of South Saskatchewan River at SE 1/4 S.5 Tp.14 R.5 W.4

Deposit	Thickness (feet)
Sand and silt, lacustrine	10
Till, yellowish brown, silty; contains gravel inclusions	20
Silt, yellow	6
Till, dark-brown, massive	5
Interbedded silt and till	5
Till, dark greyish brown; some silt and gravel beds present	50
Sand and silt; minor till inclusions; Bison occidentalis? remains found at base of unit; await result of radiocarbon age determination on some of these bones	6
Sand, some gravel beds present; a peat? bed occurs at approx. 25 feet below top of unit; the following fossils have been recovered from the upper part: a) Artiodactyl, possibly Cervus; fragment of left ramus of lower jaw with very worn 4th premolar and 2nd and 3rd molars. b) Equus sp., smaller than the modern E. caballus; left scapula, incomplete	70

Gravel, glacial ----------	3
Silt, yellow; lowermost beds darker colour; Equus sp., about 10% smaller than average for E. caballus; left metatarsal ---------	10
Saskatchewan gravels and sands; mainly sand ----------	6
Bedrock, Foremost formation (Cretaceous) ----------	10+

DRILL HOLES (logs taken from seismic shot point data)

Location	Description	Depth (feet)
Lsd.13 S. 8 Tp.2 R.14 W.4	Till	0- 60
	Gravel	60- 85
	Sandstone (bedrock)	85-150
Lsd. 4 S.15 Tp.2 R.13 W.4	Till	0- 45
	Gravel	45- 60
	Blue shale (bedrock)	60- 75
Lsd. 2 S.25 Tp.3 R.15 W.4	Sand	0- 73
	Gravel	73- 90
Lsd. 3 S. 4 Tp.4 R.15 W.4	Till	0-145
	Gravel	145-150
	Sandstone (bedrock)	150-190
Lsd. 4 S.28 Tp.1 R.13 W.4	Till	0- 80
	Fine gravel	80-100
	Sandstone (bedrock)	100-120
Lsd.13 S. 6 Tp.1 R.13 W.4	Till	0- 70
	Gravel	70- 75
	Till?	75- 90
	Gravel	90-105
	Sandstone (bedrock)	105-120
Lsd.14 S.32 Tp. 6 R.13 W.4	Brown till	0- 35
	Sand and gravel	35- 40
	Blue till	40- 88
	Shale (bedrock)	88-105
Lsd.16 S.19 Tp. 7 R.13 W.4	Till	0- 40
	Gravel	40- 44
	Till	44-190
	Sandstone and shale (bedrock)	190-210

Location	Description	Depth (feet)
Lsd.15 S.23 Tp. 6 R.13 W.4	Brown till	0-120
	Blue till	120-250
Lsd.13 S. 8 Tp. 7 R.12 W.4	Brown till	0- 90
	Blue till	90-200
Lsd.16 S.19 Tp. 7 R.12 W.4	Brown till	0- 45
	Blue till	45-195
	Shale (bedrock)	195-210
Lsd.15 S. 9 Tp. 6 R.12 W.4	Brown till	0- 65
	Blue till	65-130
	Gravel	130-180
	Shale (bedrock)	180-210
Lsd. 5 S.23 Tp. 6 R.12 W.4	Brown till	0- 70
	Blue till	70-150
	Gravel	150-165
Lsd.12 S. 7 Tp. 6 R.11 W.4	Brown till	0- 55
	Blue till	55-250
Lsd.16 S.33 Tp. 6 R.11 W.4	Till	0- 50
	Fine gravel	50- 60
	Till	60-140
	Shale (bedrock)	140-165
Lsd. 4 S.25 Tp.11 R.10 W.4	Till	0- 20
	Sand	20- 35
	Till	35-105
Lsd. 5 S.28 Tp.10 R.10 W.4	Brown till	0- 30
	Blue till	30-105
	Shale (bedrock)	105-130

PLATE 1

A. The Cypress Hills near the Alberta-Saskatchewan border. Glacial drift partly fills Graburn Gap (centre) and covers the northern escarpment (right) up to an elevation of 4500 feet. Continental ice did not extend south of Battle Creek (left-centre) which may have conducted some meltwater to the southeast into Saskatchewan (Map 1). Dense forests clothe many of the slopes in this area.

B. The Cypress Hills Plateau, south of Elkwater. The Cypress Hills conglomerate and overlying loess are well exposed here.

A

B

THE CYPRESS HILLS

PLATE 2

A. Seven Persons Coulee, an ice-marginal channel, is about a mile wide and 100 feet deep at this locality (S.12 Tp.11 R.6 W.4). Bedrock exposures can be seen along the sides of the coulee.

B. Looking westwards along Chin Coulee at S.11 Tp.7 R.13 W.4. This ice-marginal channel is a mile wide and about 200 feet deep.

A

B

ICE-MARGINAL CHANNELS

PLATE 3

A. Looking eastwards along the South Saskatchewan Canyon (Lsd.8 S.12 Tp.11 R.13 W.4), which is over a mile wide and more than 300 feet deep. The Foremost beds are exposed along the valley sides.

B. Milk River Canyon at S.9 Tp.2 R.6 W.4 is over a mile wide and more than 400 feet deep. The Oldman and underlying Foremost beds are exposed along the dissected valley sides.

A

B

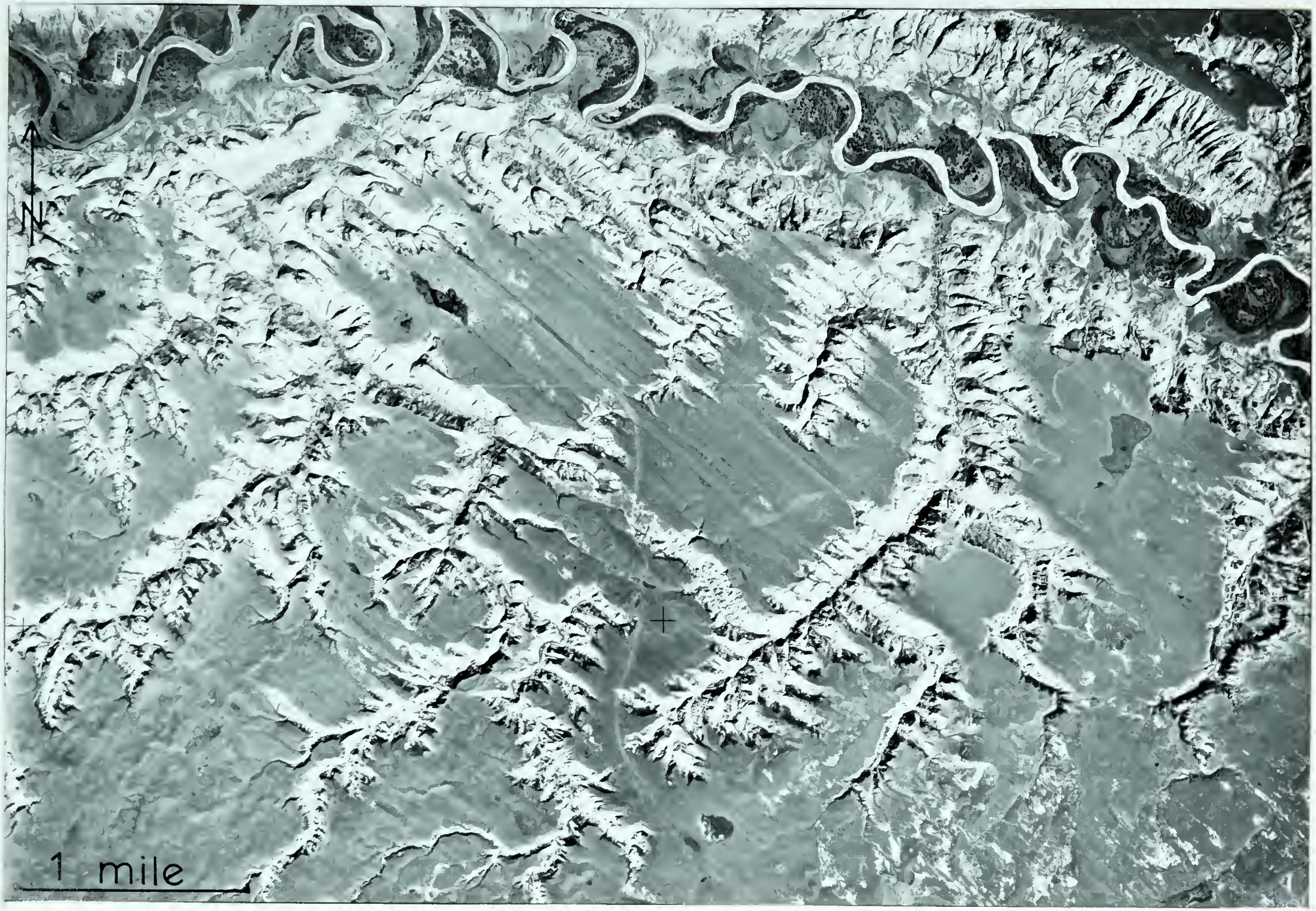
CANYONS

PLATE 4

160 - 4902
1998 - 146

Flutings in bedrock south of Milk River Canyon. The drift thickness varies from 0 to 15 feet. The dissection of the land by streams south of the Milk River largely post-dates the formation of the Milk River Canyon. Notice how the flutings have controlled the orientation of the tributary valleys.

Location: township 2, range 7



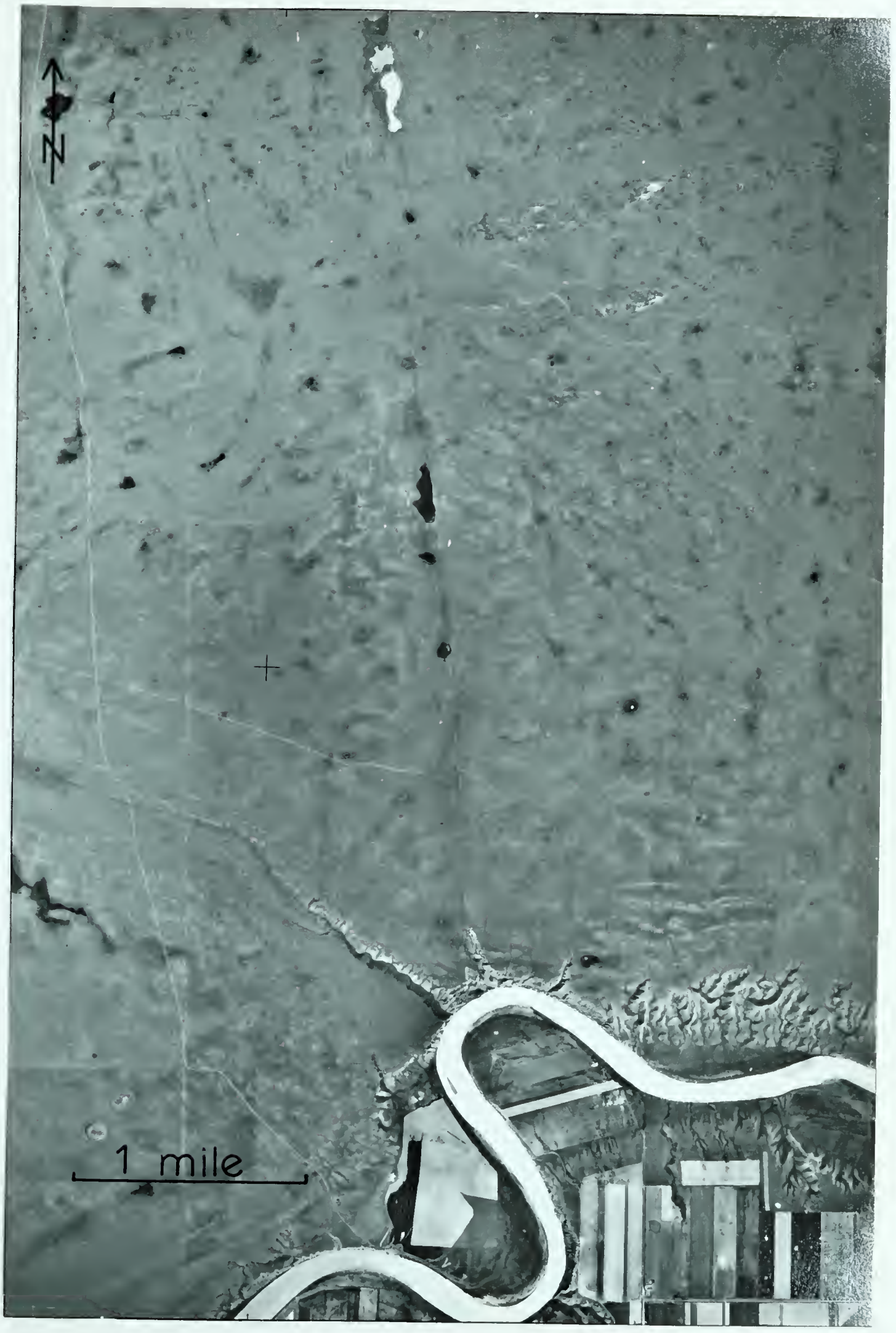
FLUTINGS

PLATE 5

160 - 4916
1926 - 88

A fault displacing glacial drift and controlling part of the course of the South Saskatchewan River.

Location: township 11, range 15



STRUCTURAL LINEAMENT

PLATE 6

160 - 4910
2131 - 21

An area of ground moraine showing the characteristic low relief and numerous undrained depressions. The till is 10-20 feet thick here and bedrock exposures can be seen along the valley walls of Forty Mile Coulee.

Location: township 7, ranges 10 and 11

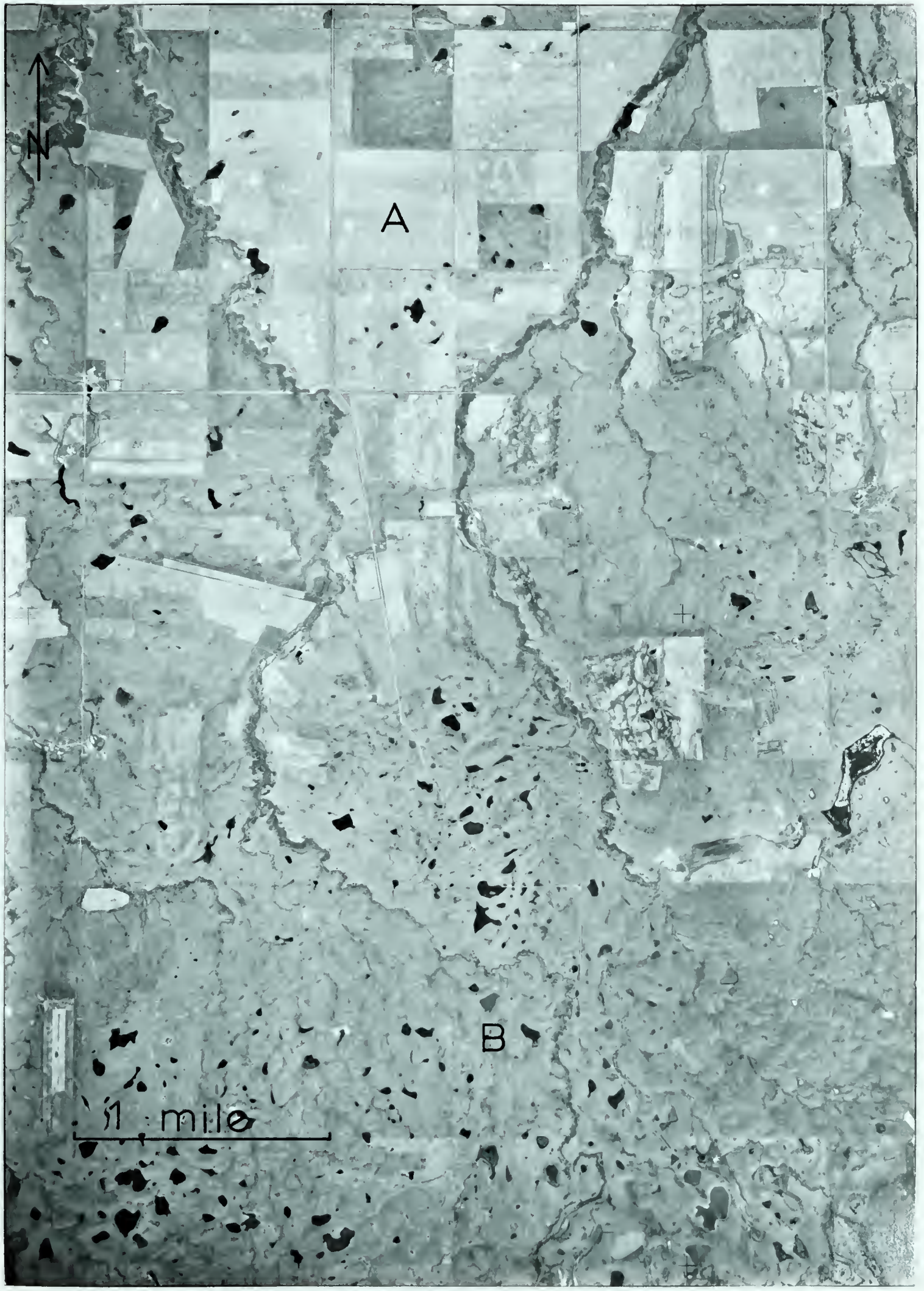
GROUND MORAINE

PLATE 7

160 - 4913B
2131 - 61

Ground moraine (A) grading uphill into hummocky disintegration moraine (B). Thin ablation till covers the ground moraine. The till is over 60 feet thick.

Location: township 9, range 2



GROUND MORAINE GRADING INTO HUMMOCKY DISINTEGRATION MORAINE

PLATE 8

160 - 4912
2194A - 50

Hummocky disintegration moraine immediately to the north of the Wild Horse End Moraine (A), near Elkwater. Closed ridges (B), linear ridges (C), and moraine plateaux (D) are shown. The local relief is greater than 25 feet and the till is more than 60 feet thick.

Location: township 8, range 3

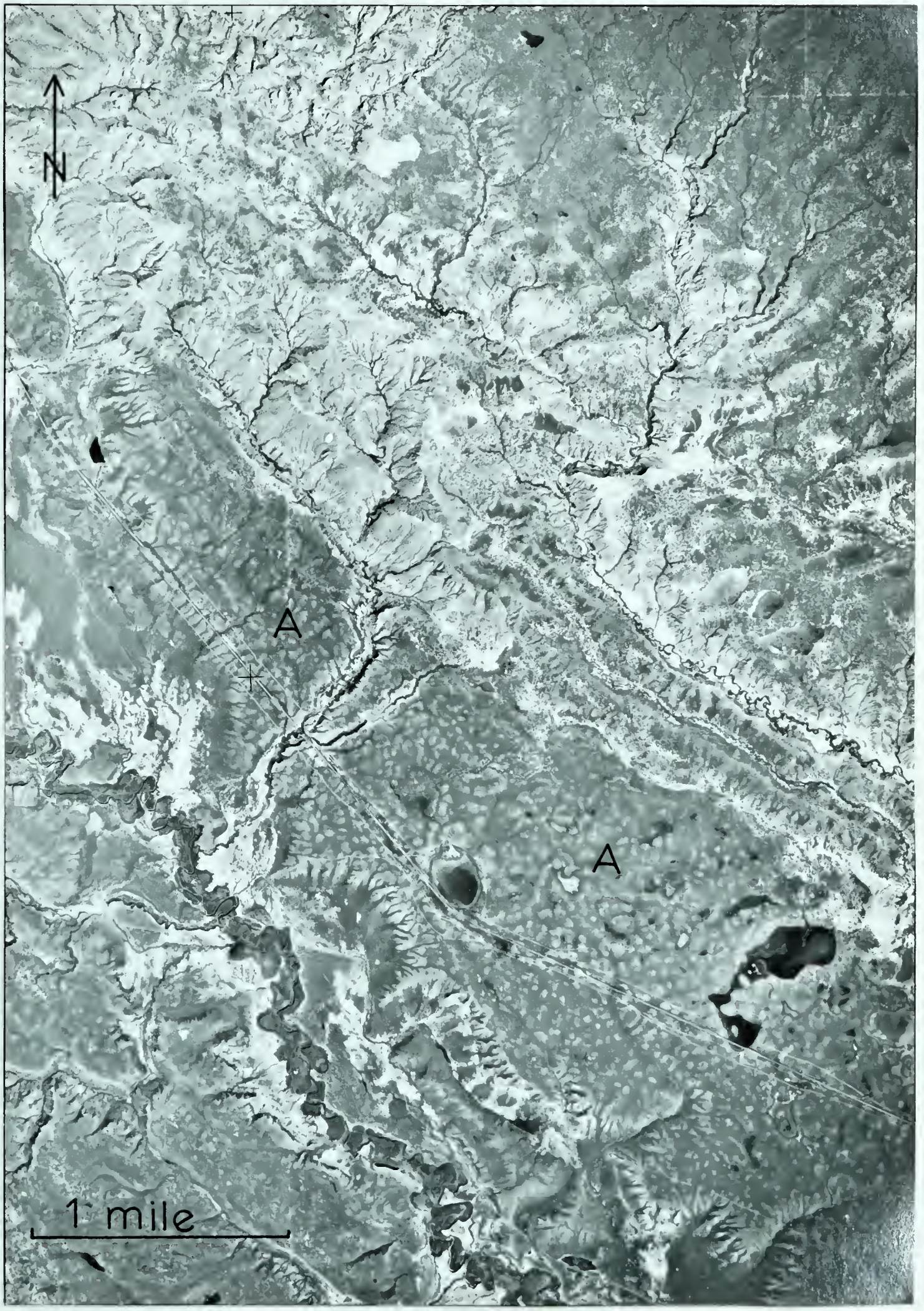
HUMMOCKY DISINTEGRATION MORAINE

PLATE 9

160 - 4905
1998 - 87

Hummocky disintegration moraine (A) with local relief considerably less than 25 feet. Only knobs are well developed; closed and linear ridges are rare or absent. The till is 10 to 20 feet thick. Note bedrock exposures to the north.

Location: township 4, ranges 3 and 4



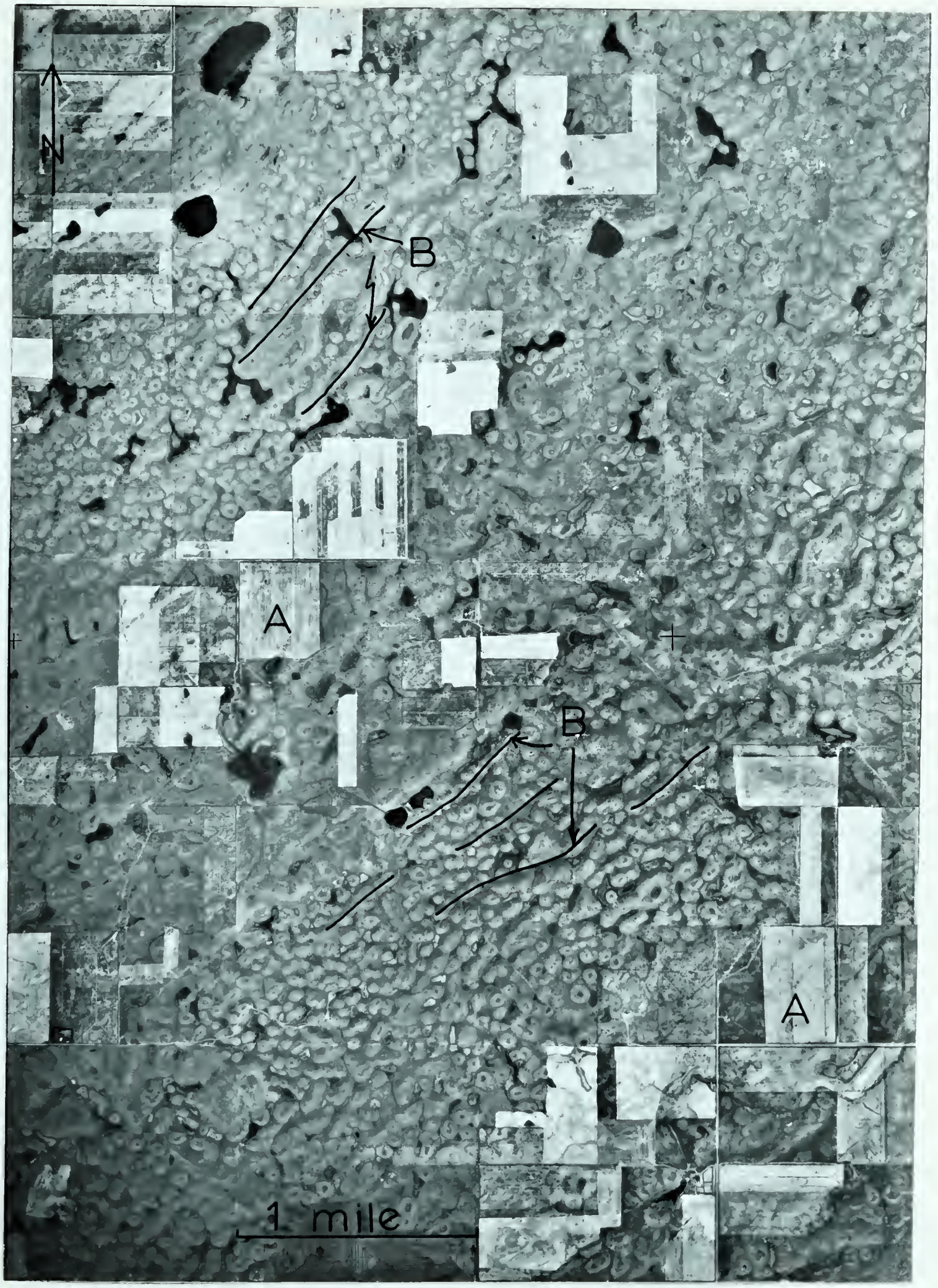
HUMMOCKY DISINTEGRATION MORAINE

PLATE 10

160 - 4909
2172 - 91

Aligned knobs, closed and linear ridges in hummocky end moraine. Lacustrine sediment (A) covers part of the moraine. The till is more than 100 feet thick, and some of the glacial lineaments are shown (B).

Location: townships 6 and 7, range 8



HUMMOCKY END MORAINE

PLATE 11

160 - 4905
1998 - 82

Ridged end moraine east of Lake Pakowki. Till ridges are the most conspicuous element. The till varies from 20 to 50 feet thick. Note bedrock exposures in valleys (A).

Location: township 4, ranges 5 and 6

RIDGED END MORAINE

PLATE 12

160 - 5000
1922 - 120

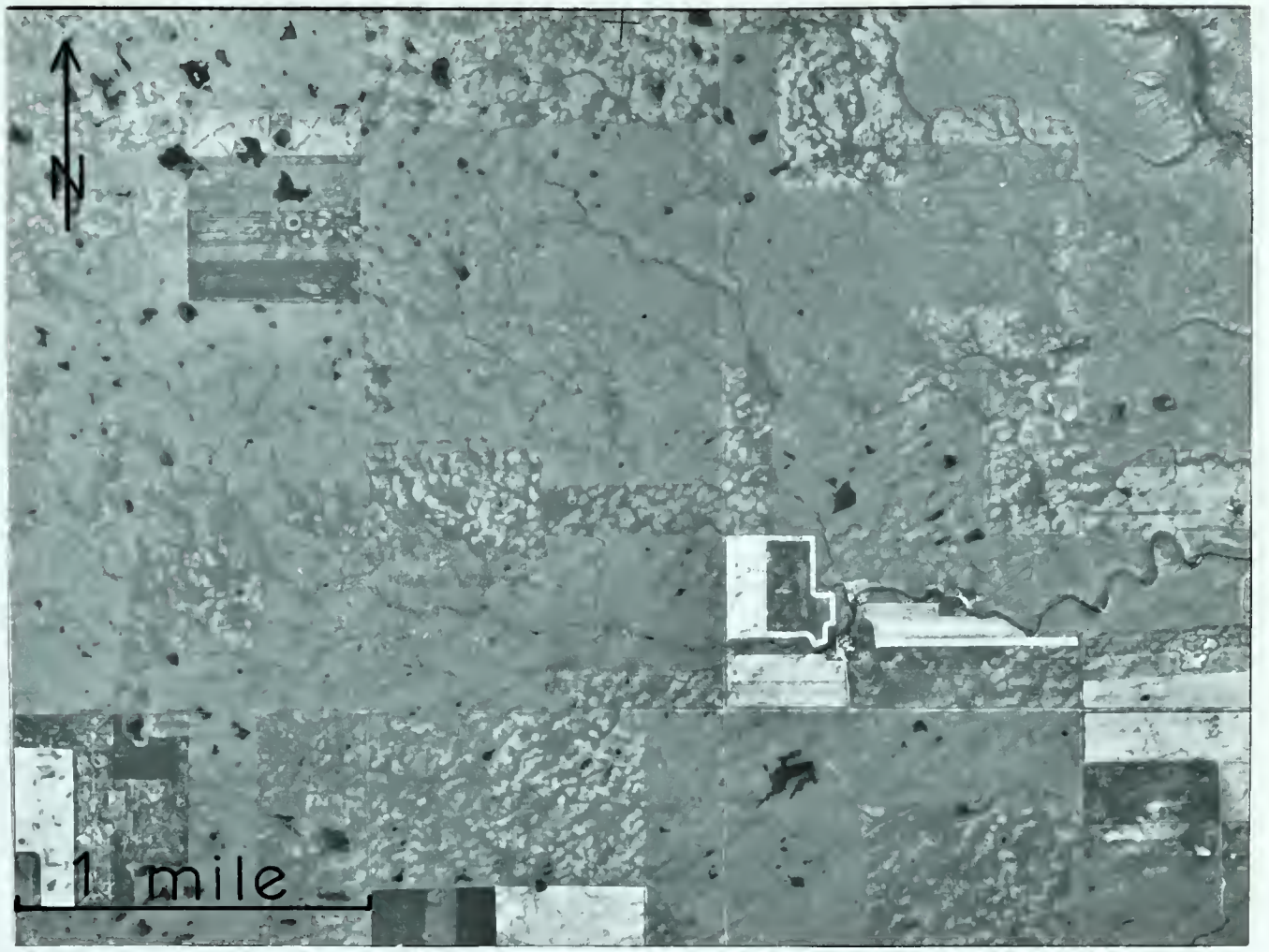
Washboard moraine north of Seven Persons. Transverse till ridges are up to 10 feet high and 100 to 300 feet apart. The till is more than 50 feet thick.

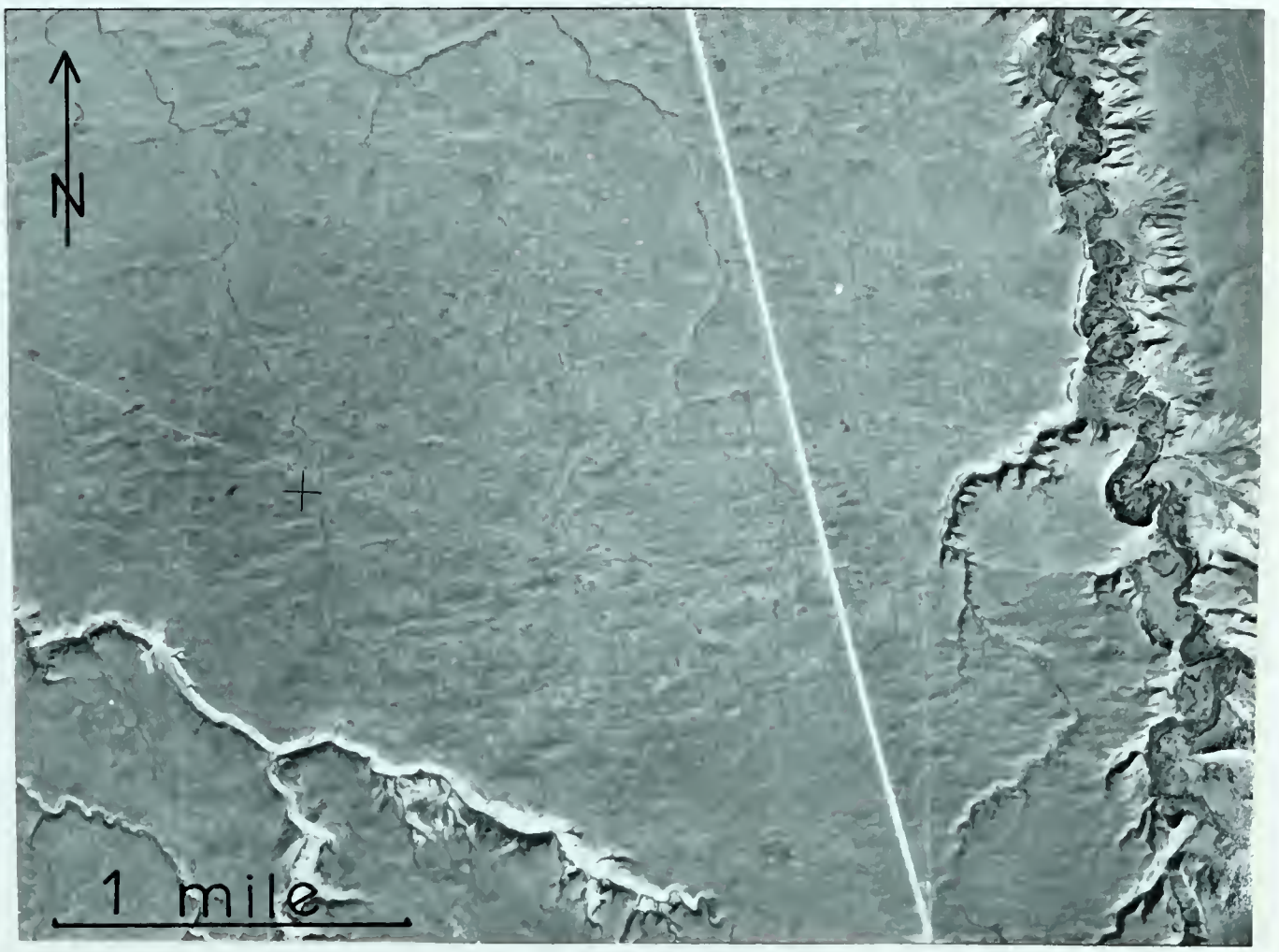
Location: township 11, range 7

160 - 4902
1998 - 136

Washboard moraine south of Milk River. The ridges vary in height from 2 to 10 feet. The till is 10 to 30 feet thick.

Location: township 2, range 10





WASHBOARD MORAINE

PLATE 13

160 - 4907
2456 - 42

Linear disintegration ridges composed entirely of gravel and sand along the northwestern shore of Lake Pakowki. The ridges parallel the former margin of the stagnant ice.

A, hummocky end moraine; B, Etzikom Coulee; C, confluent junction of ridges.

Location: township 5, range 8

LINEAR DISINTEGRATION RIDGES

PLATE 14

160 - 4902
1998 - 152

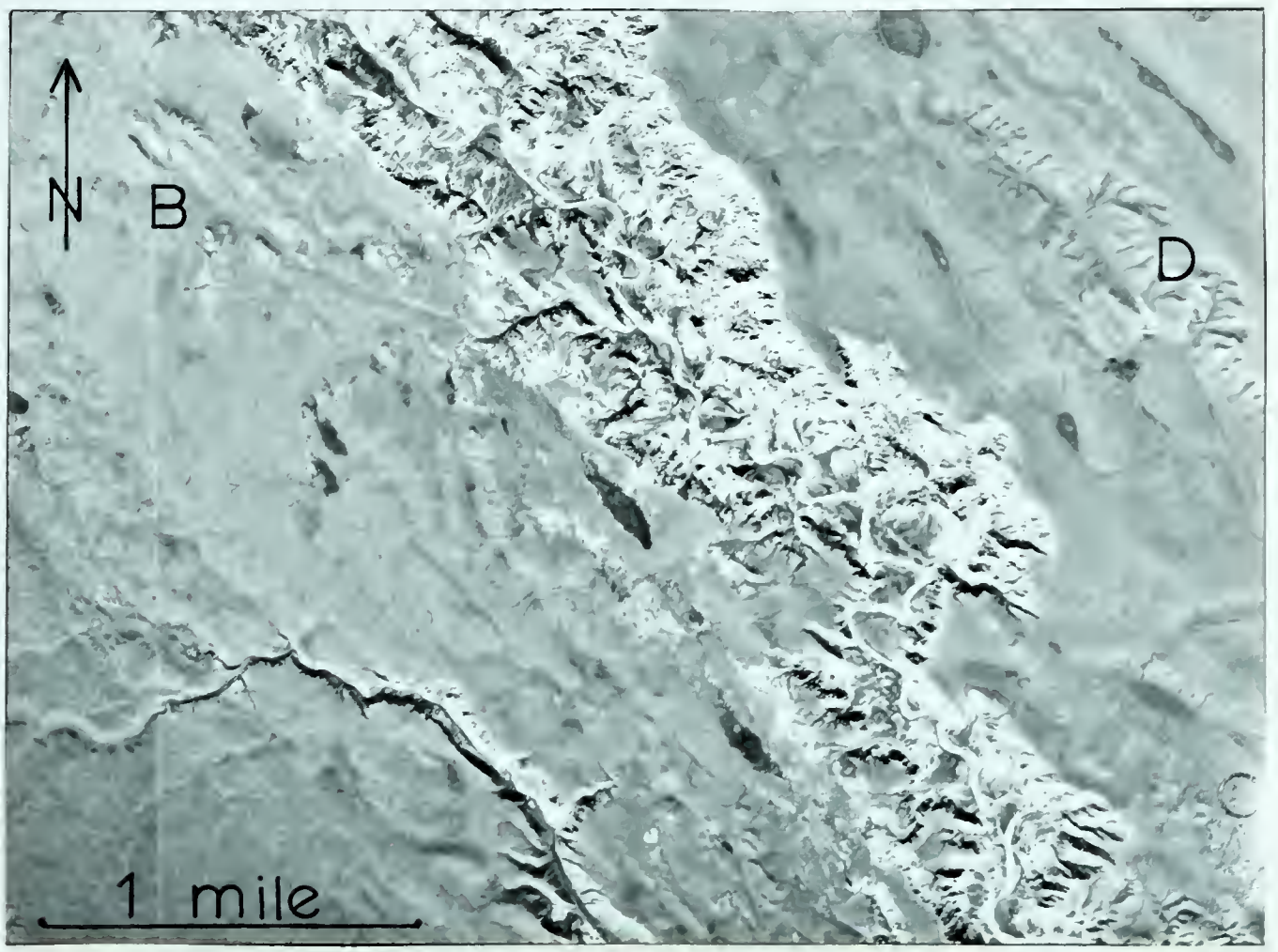
Drumlinoid ridge (A), 25 feet high and composed of gravel and sand. The drift is thin in this area (Lost River district) and consists mainly of outwash gravel and sand with patches of till. Bedrock is exposed at the surface in places.

Location: township 2, range 5

160 - 4901B
2191 - 143

Drumlins (B), about 50 feet high and composed of gravel and sand, associated with ice-contact features -- kames (C) and an esker (D). Lost River flows across the area.

Location: township 1, range 4



DRUMLINS AND DRUMLINOID RIDGES

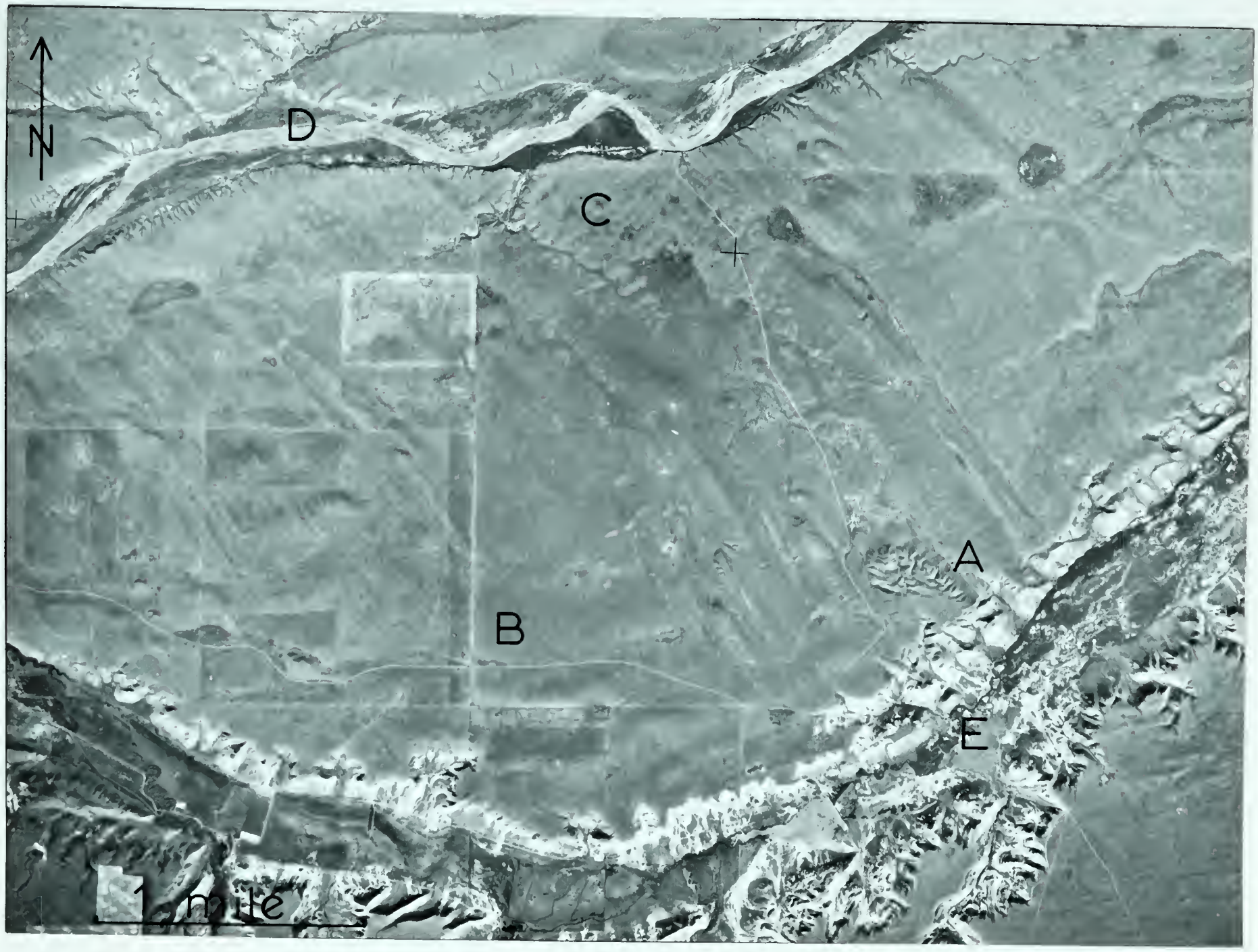
PLATE 15

160 - 4902
1998 - 133

A swarm of drumlins, composed of gravel and sand. Drumlin A is about 600 yards wide and over 50 feet high. The ice flowed to the southeast. Note bedrock exposures (Milk River formation) along Dead Horse Coulee.

B, outwash sands; C, till; D, Milk River; E, Dead Horse Coulee, an abandoned ice-marginal channel.

Location: township 2, range 11



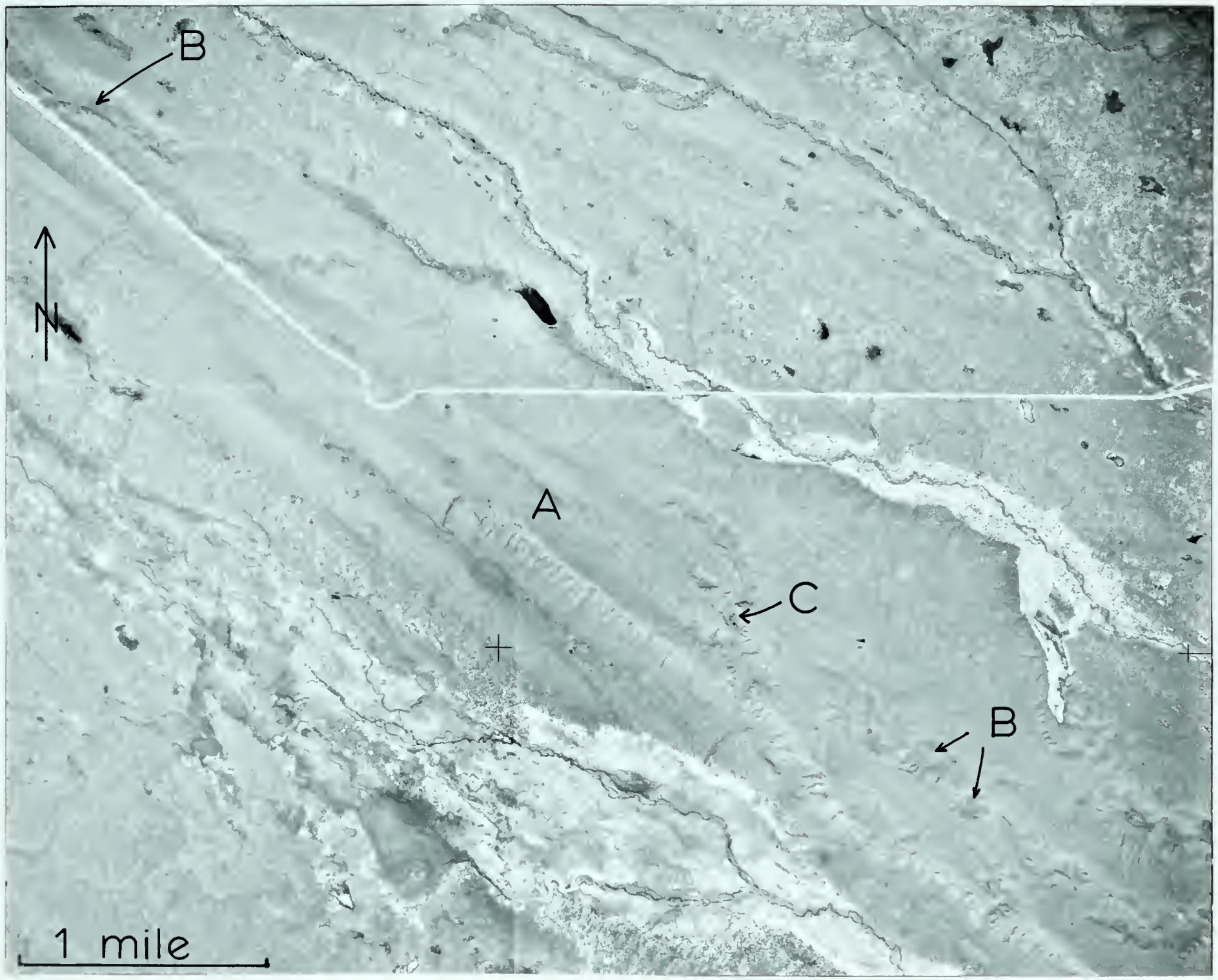
DRUMLINS

PLATE 16

160 - 4901B
2191 - 145

A relatively straight esker (A) oriented parallel to the direction of ice movement and pitted by kettles (B) and a channel (C). The latter was formed by a superglacial stream. This esker is more than 12 miles long, approximately a mile wide, and in places 50 feet above the surrounding prairie level.

Location: township 1, range 3



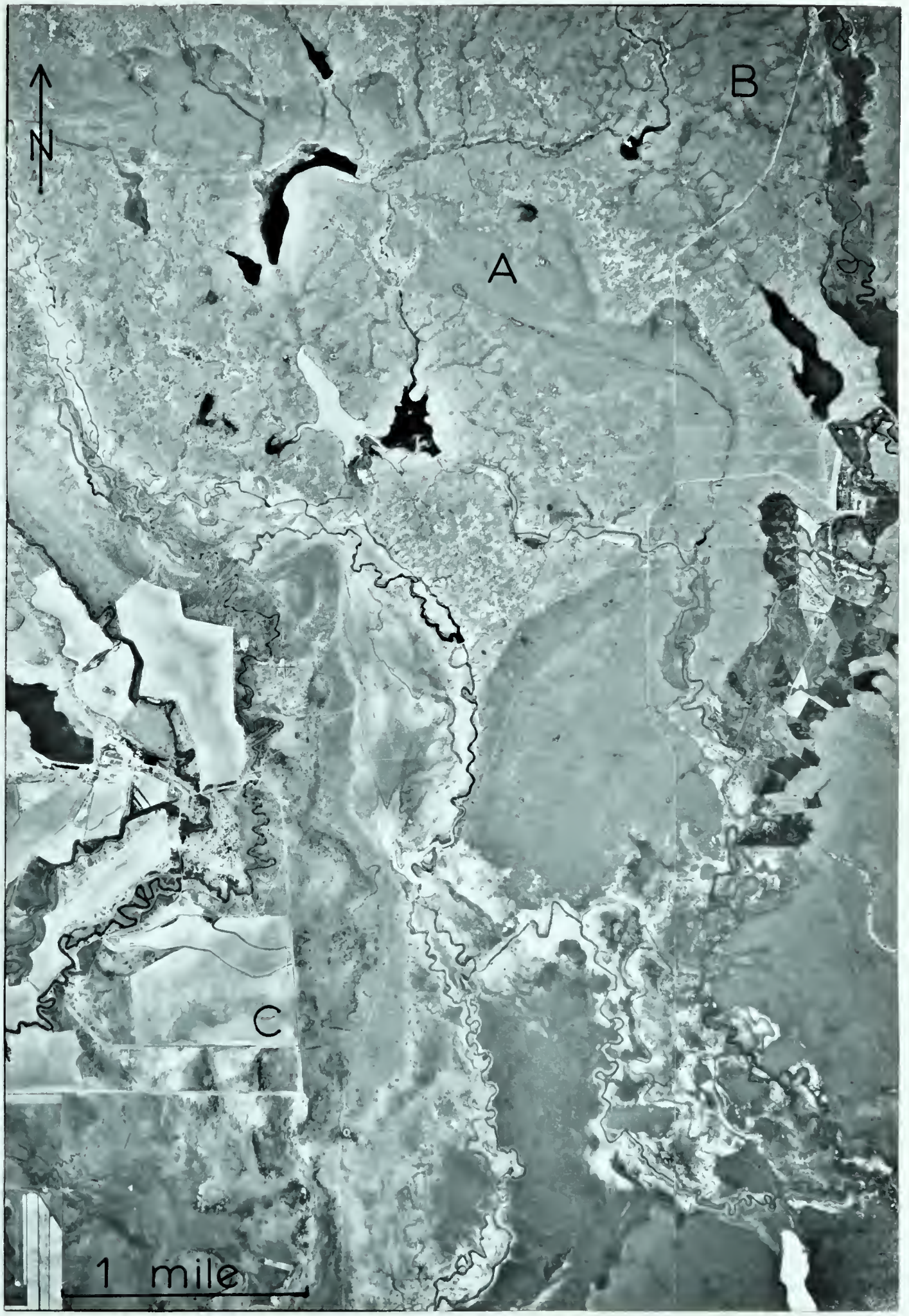
ESKER

PLATE 17

160 - 4901
2273 - 111

A sinuous esker (A), lying on hummocky end moraine (B), and terminating in Glacial Lake Wild Horse (C). Note the tonal contrast between the sand and gravel of the esker and the till of hummocky end moraine.

Location: townships 1 and 2, range 2



SINUOUS ESKER

PLATE 18

A, B. Three feet of loess on the Cypress Hills conglomerate, whose uppermost beds have been deformed by frost action. Involutions and the vertical attitude of the long axes of pebbles are well shown in B.

Location: Lsd.12 S.9 Tp.8 R.3 W.4

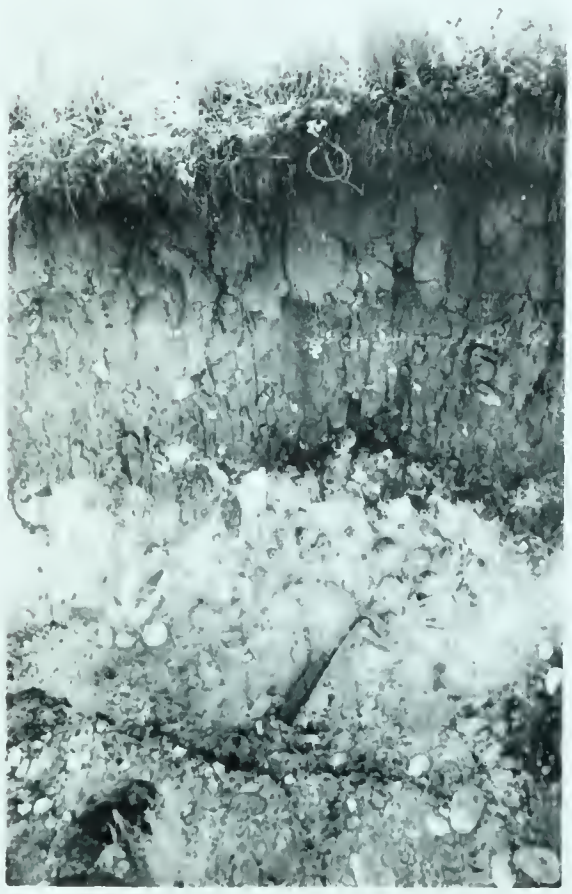
C. Till-like fabric of the Cypress Hills loess. All the pebbles are quartzites and were elevated into the loess by frost action from the underlying Cypress Hills conglomerate.

D. Eight feet of Cypress Hills loess on deformed beds of the Cypress Hills conglomerate. This section has now been destroyed.

Location: Lsd.8 S.25 Tp.8 R.2 W.4

A

B



C

D

CYPRESS HILLS LOESS

PLATE 19

160 - 4900
2272 - 26

Lake Wild Horse sediments (A) situated to the north of a large esker (B).

C, till; D, Wild Horse.

Location: township 1, range 1

GLACIAL LAKE WILD HORSE

PLATE 20

160 - 4911
2194A - 78

Small ice-marginal meltwater channels excavated in ground moraine.

They are approximately 300 feet wide and about 10-20 feet deep.

Location: township 8, range 13

ICE-MARGINAL MELTWATER CHANNELS

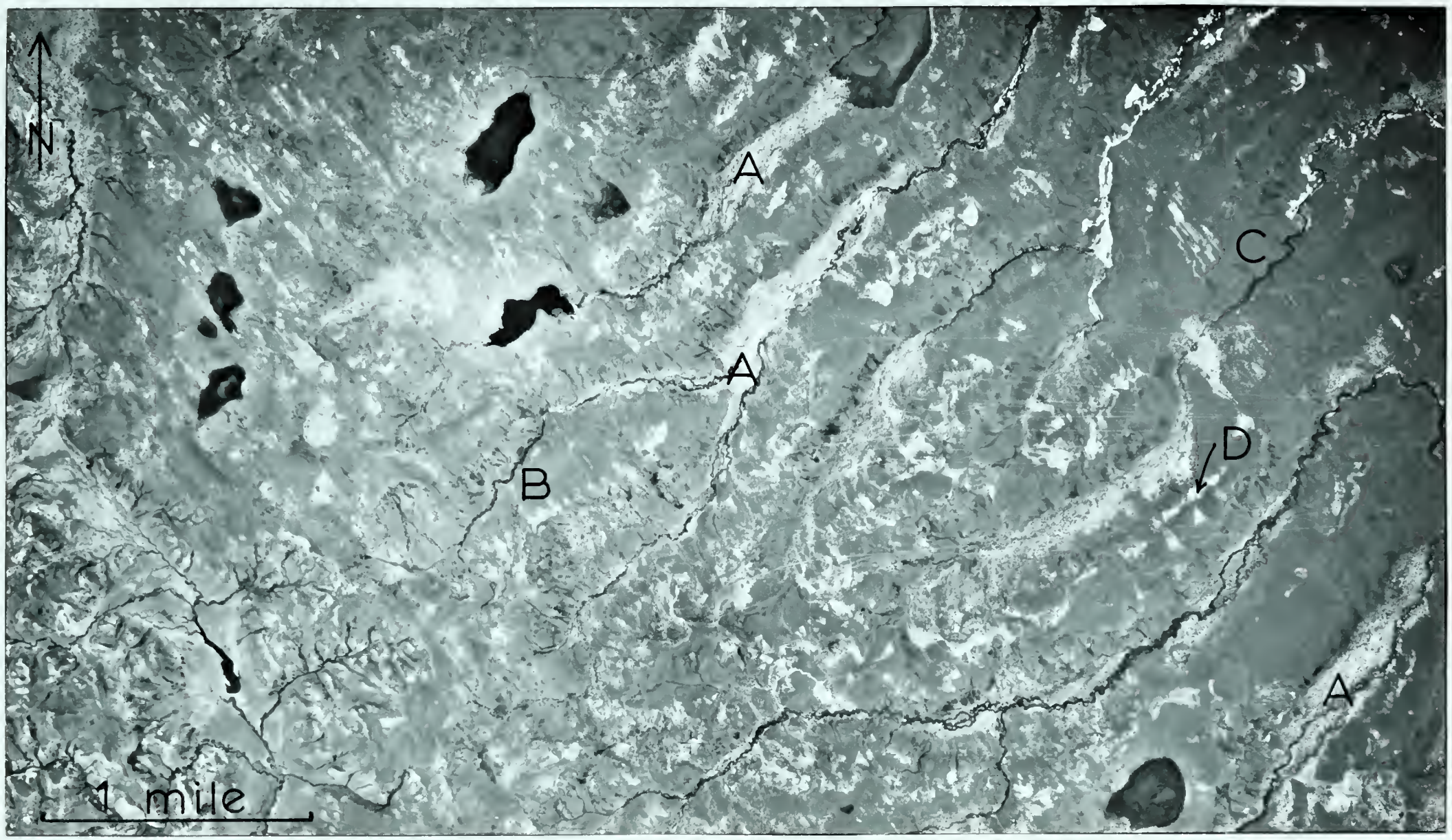
PLATE 21

160 - 4900
2272 - 14

Ill-defined ice-marginal meltwater channels (A) eroded into bedrock. Thin till caps the ridges and flutings extend across both the ridges (B) and channels (C).

C, badland escarpment and pediment (in bedrock).

Location: township 1, range 7



ERODED PLAIN

PLATE 22

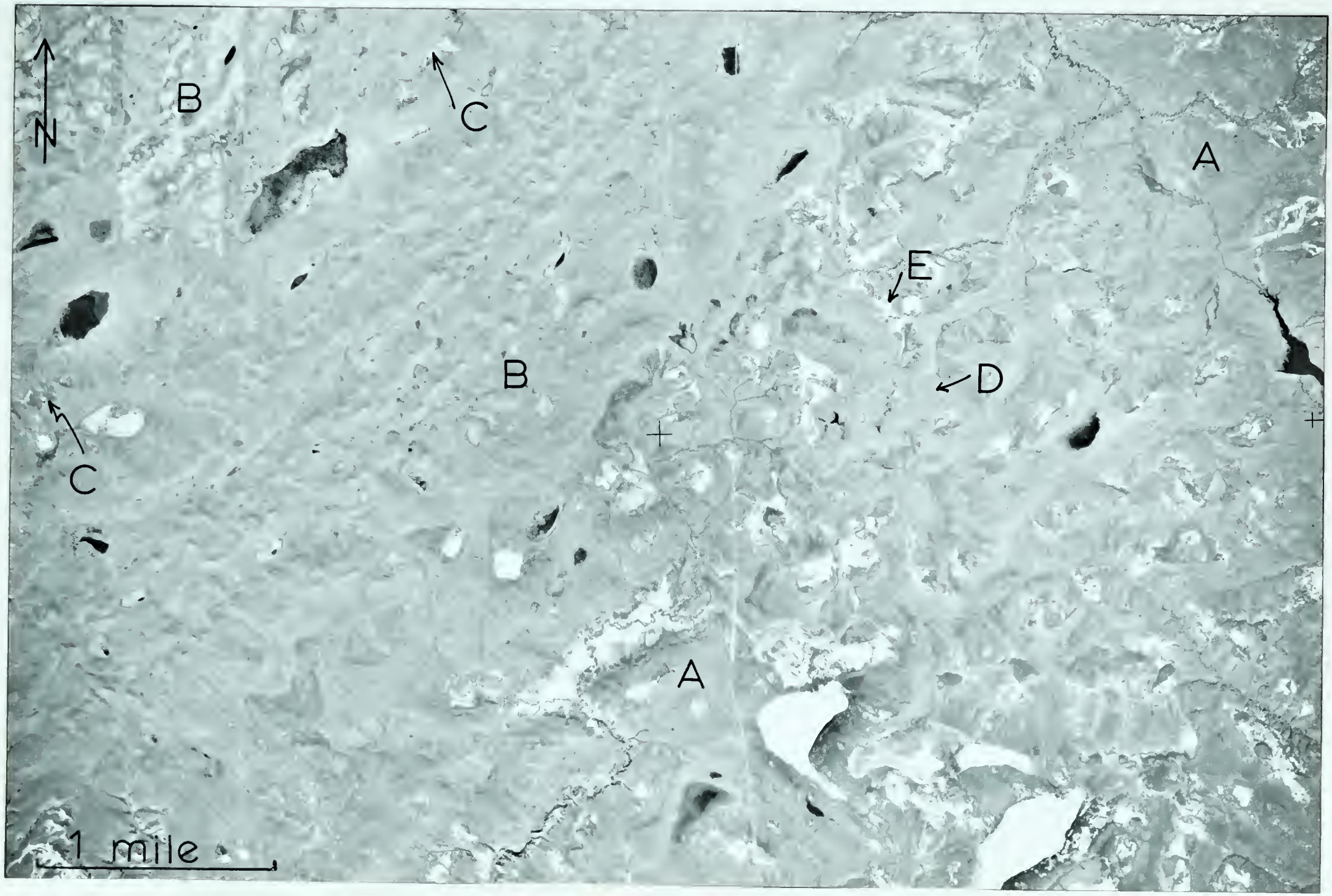
160 - 4904A
2191 - 97

Eroded plain (A) partly buried by the Pakowki End Moraine (B).

"Windows" of the eroded plain occur in the end moraine (C).

D, sand dunes; E, badland escarpment and pediment (in bedrock).

Location: township 3, range 5



ERODED PLAIN

PLATE 23

160 - 4907
2456 - 46

Lobate sheets of sand with superimposed dunes (A) overlying ground moraine (B) and hummocky moraine (C) east of Lake Pakowki. The sandy area is now stabilised by grasses, shrubs and trees.
D, parabolic dunes; E, transverse dunes; F, reactivated dunes

Location: township 5, ranges 6 and 7

DUNES EAST OF LAKE PAKOWKI

PLATE 24

160 - 4915
2060 - 9

Parabolic dunes, south of the Oldman River, developed by west-southwesterly winds. Lacustrine sand overlies till in this area. Note the terraces along the Oldman River Valley.

Location: township 11, range 14

DUNES

PLATE 25

A. Hummocky disintegration moraine north of Elkwater (cf. Plate 8).

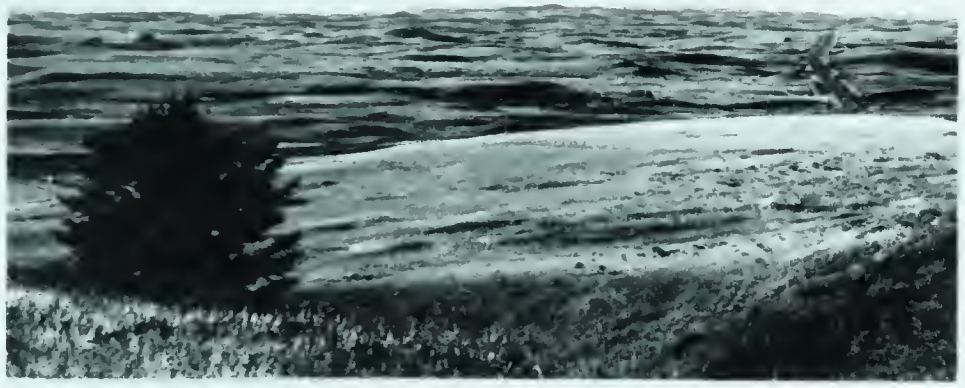
B. A hummock composed of till, gravel, and sand (ablation drift) in an area of hummocky disintegration moraine.

Location: Lsd.5 S.28 Tp.7 R.4 W.4

C. A drumlinoid ridge just east of Lost River (S.1 Tp.2 R.5 W.4), composed of gravel and sand.
Compare Plate 14, feature A.

D. A swarm of drumlins, west of Lost River, composed of gravel and sand. The stoss ends face the observer. These drumlins are shown on Plate 14, feature B.

Location: S.16 Tp.1 R.4 W.4



A

B

C

D

SOME GLACIAL LAND FORMS

PLATE 26

Elongate dolomite stones showing pronounced striations parallel to their long axes. This indicates that whilst in the ice, the stones had their long axes parallel to the direction of ice movement. The relative ages of the striations can be seen; the youngest mainly parallel the present long axes of the stones. Other striation directions may in part be related to the abrasional history of the stones whilst in the ice.

STRIATIONS ON DOLOMITE STONES

PLATE 27

A, B. Deformed sands overlain by till. The direction of ice movement is given by the overturned fold in the sands (A) and by linear sole marks on the bottom of the till sheet (B). This lineation parallels the direction of ice movement.

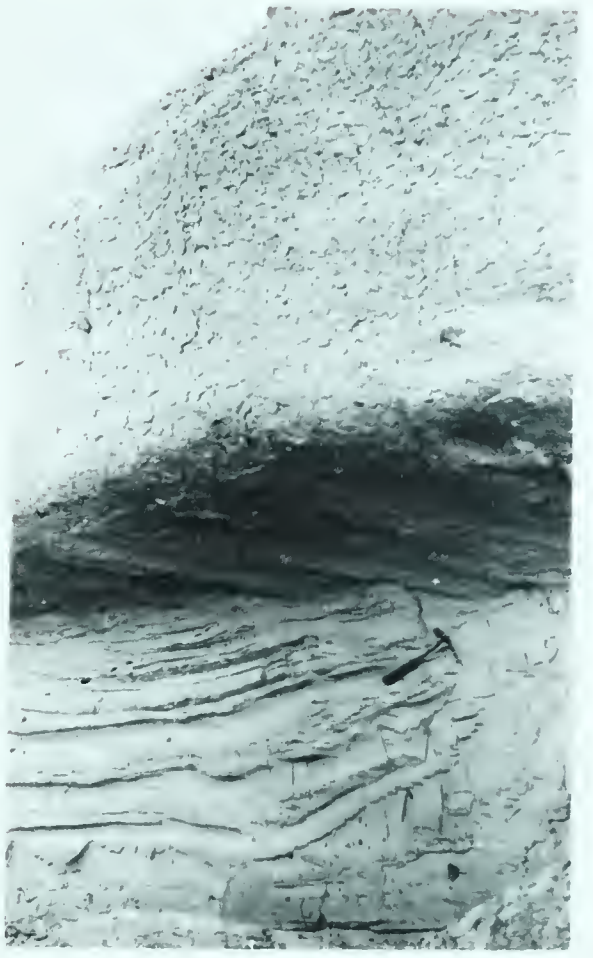
Location: Lsd.1 S.1 Tp.12 R.11 W.4

C. An oriented block of till with a lineation on the face that partly enclosed a sand lens in the till. This lineation parallels the preferred long-axis orientation of the pebbles in the till block and hence is parallel to the direction of ice movement (Figure 27, sample 561).

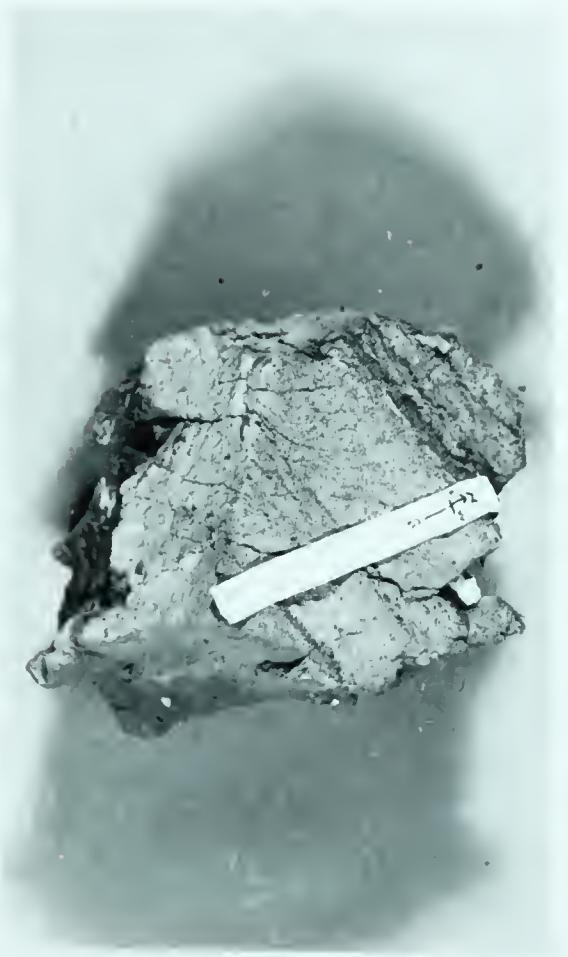
D. Erratics of Cypress Hills conglomerate. At least 25 such erratics were counted in this valley.

Location: Lsd.13 S.17 Tp.5 R.2 W.4

A



B



C

D

FEATURES INDICATING DIRECTION OF ICE MOVEMENT

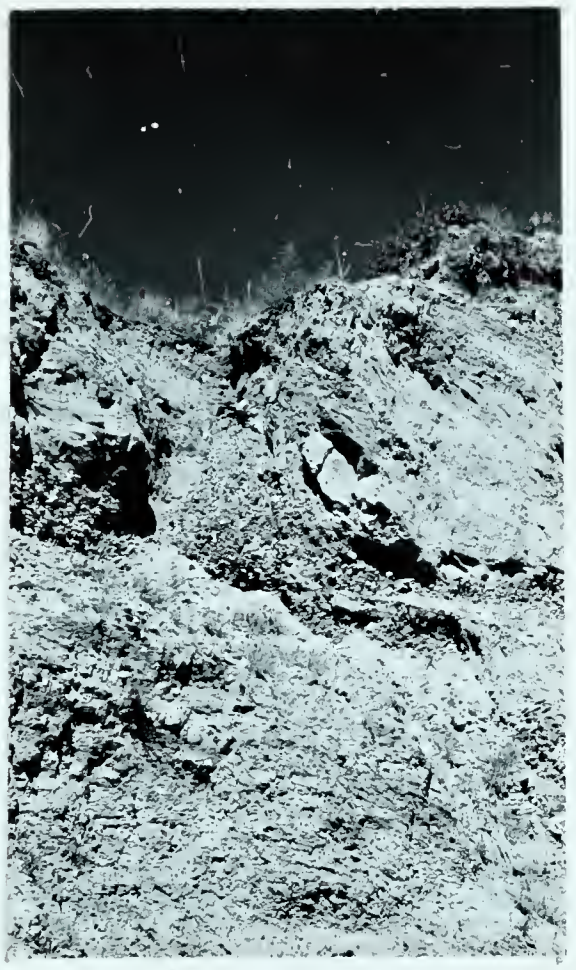
PLATE 28

A, B. Periglacial (frost action) structures in the Saskatchewan gravels and sands that are exposed along the Oldman River Valley. A, an involution (Lsd.12 S.20 Tp.11 R.14 W.4); b, a horizon of deranged pebbles whose long axes are now in a vertical position (Lsd.6 S.23 Tp.11 R.15 W.4).

C. Interbedded sands, silts and clays that were deposited in a proglacial lake which occupied the Bullshead Creek preglacial valley just prior to glaciation of the area. These lacustrine sediments were deformed by the overriding glacier.

Location: Lsd.16 S.31 Tp.9 R.5 W.4 Hammer gives scale.

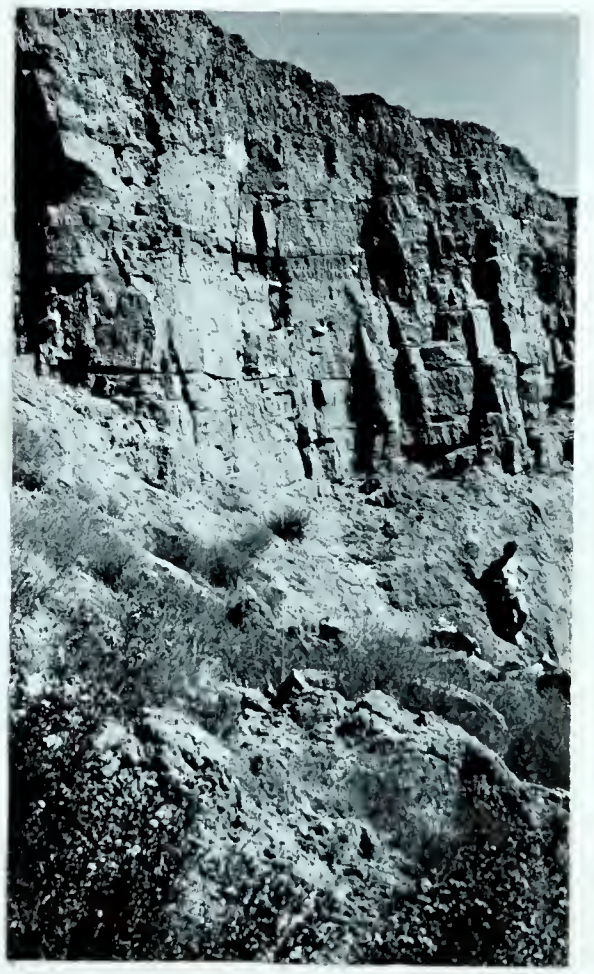
D. Three distinct till sheets exposed at Lsd.5 S.23 Tp.11 R.3 W.4. These three tills can be traced westwards along Gros Ventre Creek for a distance of 8 miles.



A

B

C



D

PLEISTOCENE DEPOSITS OF THE FOREMOST-CYPRESS HILLS AREA

PLATE 29

A. Manyberries volcanic ash -- a 6-inch thick ash bed (white on photograph) overlain by 25 feet of lacustrine sand, silt, and clay. Till is exposed at the foot of the cliff. The town of Manyberries is seen in the background.

Location: Lsd.14 S.13 Tp.5 R.6 W.4

B. Post-depositional deformation of the Manyberries volcanic ash. The minor faulting and sudden steepening of the dip of the ash bed and closely associated lacustrine sediment near the assistant seem to have been produced by localised collapse as a result of melting ice at depth. If this is the case, then the volcanic ash is approximately contemporaneous with the disappearance of the last glacier to affect the Manyberries district.

A

B

MANYBERRIES VOLCANIC ASH

PLATE 30

A. Overturned fold. This till is most probably of Pakowki age and was deformed by the overriding glacier that deposited the Etzikom End Moraine.

Location: Lsd.13 S.14 Tp.11 R.3 W.4

B. A fold in till at Lsd.8 S.16 Tp.10 R.4 W.4

C. "Flame" structures in till. Slices of the lower dark till have been incorporated into the upper till. Lenses of non-glacial gravel occur near the base of the lower till, which sits on the Bearpaw formation.

Location: Lsd.13 S.18 Tp.10 R.2 W.4

A

B

C

STRUCTURES IN TILL

LEGEND

QUATERNARY

RECENT

18 — Aeolian deposits: sand and silt; parabolic dunes; blow outs

PLEISTOCENE AND RECENT

17 — Eroded slope: mainly bedrock; some colluvium; extensive slumping. Present along meltwater channels and recent valleys but not indicated on map.

PLEISTOCENE

Glacio-Lacustrine

16 — Lacustrine sediments: sand, silt and clay; till in places

15 — Lacustrine sediments: sand, silt and clay; some gravel; in places covered by recent lacustrine sediment and alluvium. 15a, deltaic sediments: gravel and sand.

Glacio-Fluvial

14 — Undifferentiated outwash gravel, sand and till; bedrock exposed in places.

13 — Outwash and alluvium: gravel and sand; some silt

12 — Outwash: gravel and sand on Cypress Hills formation; large Laurentian erratics present, including dolomite

11 — Meltwater channel sediments: gravel, sand, silt and clay; terraces present and lower parts covered by recent alluvium, colluvium and lacustrine sediment.

10 — Eroded plains: in part scoured by meltwater: till, gravel, sand, silt and clay; bedrock exposures common; extensive badland.

9 — Esker: gravel and sand

8 — Kame: gravel and sand

Aeolian

7 — Loess: unconsolidated sand, silt and clay overlying bedrock; generally less than 5 feet thick; slightly deformed by frost action; bedrock exposures common on southern slope of Cypress Hills; unglaciated.

Glacial

6 — Bedrock upland veneered with till; some gravel and sand in places.

5 — Patches of glacial drift, including Laurentian erratics, on bedrock.

4 — Hummocky and ridged end moraine: mainly till; some gravel and sand; aligned knobs, linear and closed disintegration ridges; large to medium local relief.

3 — Washboard moraine: mainly till; aligned ridges; small local relief -- less than 10 feet.

2 — Hummocky disintegration moraine: mainly till; knobs, closed and linear disintegration ridges; large to medium local relief.

1 — Ground moraine: mainly till -- unsorted rocks, sand, silt and clay; patches of lacustrine and outwash sand, silt and clay; local relief less than 10 feet.

Bedrock formations: mainly sandstone and shale with some coal; conglomerate caps the Cypress Hills.

Meltwater channel (includes spillway and ice-marginal channel)

Buried channel (glacial)

Subglacial tunnel

Postulated direction of meltwater flow

Direction of ice movement as determined by petrofabric analysis: a, uppermost till; b, lowermost till; c, grooves on bottom of uppermost till — b

Drumlin or drumlinoid ridge: direction of ice movement indicated by arrow

Fluting: the staff parallels direction of ice movement

Glacial lineaments: dominant orientation parallels former positions of ice front

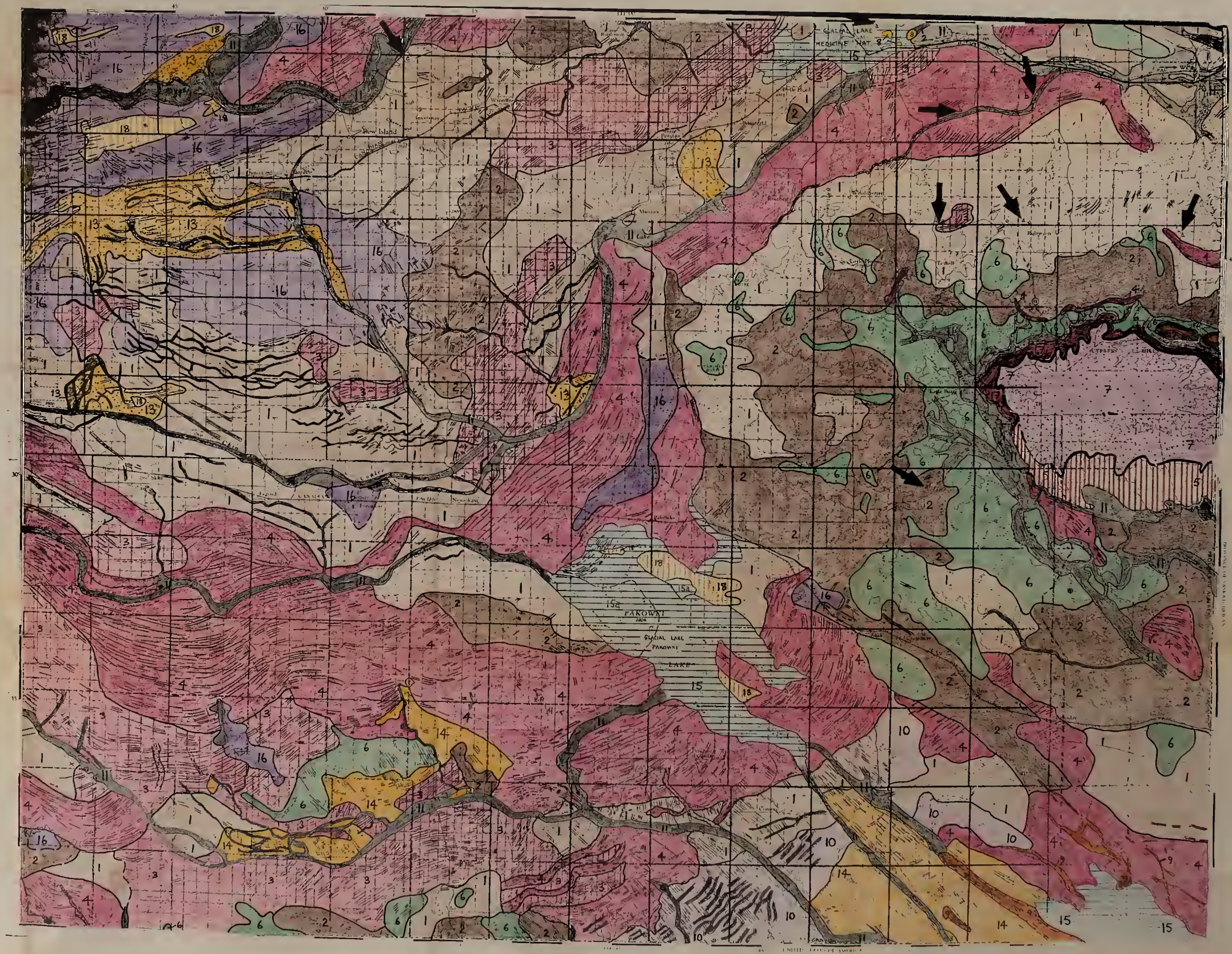
Site of large erratic blocks of Cypress Hills conglomerate

Scale in miles

4 3 2 1 0 4 8

Geology by J.A. Westgate 1961-63

SURFICIAL GEOLOGY OF THE FOREMOST — CYPRESS HILLS AREA, ALBERTA



LEGEND

QUATERNARY

RECENT

25 — Alluvium: gravel, sand, silt and clay

24 — Lacustrine sediments: silt and clay

23 — Aeolian deposits: sand

PLEISTOCENE AND RECENT

22 — Colluvium and alluvial fan: sand, silt and clay mixed

21 — Eroded slope: mainly bedrock; some glacial drift and colluvium; minor slumping

20 — Slump: mainly bedrock materials involved; some glacial drift and colluvium

19 — Thickly wooded slope, slump and colluvium

PLEISTOCENE

GLACIO-LACUSTRINE

18 — Lacustrine sediments: sand, silt and clay; till in places; some loess may be present

GLACIO-FLUVIAL

17 — Outwash: gravel and sand; quartzites abundant

16 — Ice-marginal channel deposits: silt and clay; commonly associated with recent lacustrine sediment

15 — Ice-marginal channel deposits: gravel and sand

14 — Kame ridge: gravel, sand, and silt; pockets of till

13 — Collapsed ice-contact stratified drift: sand, silt and clay; some gravel

AEOLIAN

12 — Loess: uncansolidated sand, silt and clay overlying the Cypress Hills Formation; generally less than 5 feet thick; slightly deformed by frost action

GLACIAL

11 — Controlled linear disintegration ridge: till; some gravel and sand

10 — Bedrock upland veneered with till: surface expression of drift commonly controlled by bedrock; gravel and sand in places

9 — End moraine: ridges of till, gravel and sand; aligned closed disintegration ridges; some knobs and kettles

8 — Washboard moraine: parallel, arcuate till ridges; local relief less than 5 feet

7 — Hummocky disintegration moraine: mainly till; well-defined knobs and kettles, closed and linear disintegration ridges; large local relief

6 — Hummocky disintegration moraine: mainly till; knobs, closed and linear disintegration ridges; medium local relief

5 — Ground moraine: mainly till; patches of lacustrine and outwash sand, silt and clay; some knobs, closed and linear disintegration ridges; small local relief -- less than 10 feet

4 — Ground moraine: mainly till -- unsorted rocks, sand, silt and clay; patches of lacustrine and outwash sand, silt and clay; local relief less than 10 feet

CRETACEOUS, TERTIARY AND QUATERNARY

3 — Patches of outwash gravel and Laurentian erratics on bedrock hills capped with Cypress Hills Formation

2 — Unglaciated bedrock veneered with loess: south of Cypress Hills uppermost 50 feet deformed by movement on Battle and Whitemud clays (low-angle gravity slide)

1 — Bedrock with patches of glacial drift including Laurentian erratics

TERTIARY

B — Cypress Hills and Ravenscrag Formations: conglomerate (mainly quartzite pebbles); sandstone and bentonitic clay

CRETACEOUS

A — Frenchman, Battle, Whitemud, Eastend and Bearpaw Formations: sandstone, shale, bentonitic clay and coal

Geological boundary -- definite .....

Geological boundary -- approximate .....

Ice-marginal channel .....

Postulated direction of meltwater flow .....

Limit of glacierization .....

Slump fractures .....

Glacial lineaments .....

Geology by J.A. Westgate

Main highway .....

Local road, well travelled .....

Local road, not well travelled .....

Trail .....

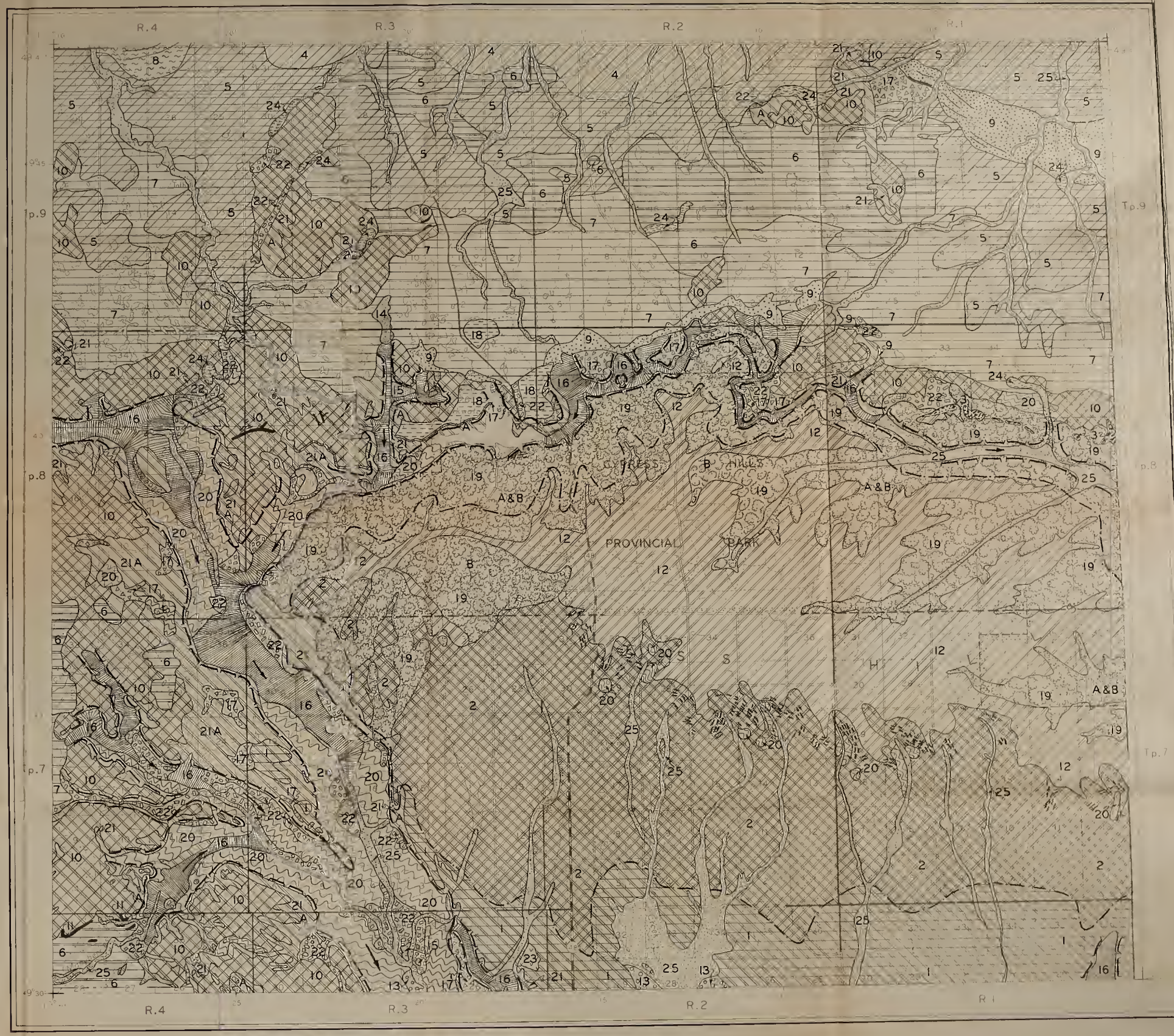
Railway .....

Irrigation ditch .....

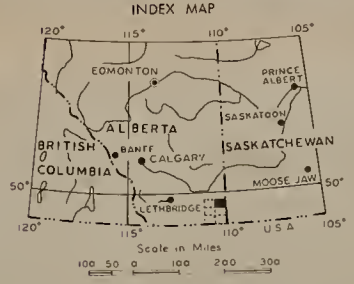
Township boundary .....

Section line .....

Cartography taken from Department of Lands and Forests, Alberta, Aerial Survey sheet No. 72E - 9



INDEX MAP



SURFICIAL GEOLOGY

ELKWATER DISTRICT, ALBERTA

WEST OF FOURTH MERIDIAN

Scale: One Inch to One Mile 1/63,360

1 3/4 1/2 1/4 0 1 2 3

LEGEND

QUATERNARY

RECENT

- 15 — Alluvium: sand, silt and clay; some gravel
- 14 — Lacustrine sediments: sand, silt and clay

PLEISTOCENE AND RECENT

- 13 — Colluvium and alluvial fan: sand, silt and clay mixed
- 12 — Eroded slope: mainly bedrock; some glacial drift and colluvium; minor slumping
- 11 — Slump: mainly bedrock materials involved, some glacial drift and colluvium

PLEISTOCENE

GLACIO-LACUSTRINE

- 10 — Lacustrine sediments: sand, silt and clay; till in places; includes recent lacustrine sediment and alluvium

GLACIO-FLUVIAL

- 9 — Ice-marginal channel deposits: silt and clay; commonly associated with recent lacustrine sediment

GLACIAL

- 8 — Controlled linear disintegration ridge: till; some gravel and sand
- 8 — Bedrock upland veneered with till: surface expression of drift commonly controlled by bedrock
- 6 — End moraine: aligned till ridges; large to medium local relief
- 5 — Hummocky end moraine: mainly till; aligned closed disintegration ridges; large local relief
- 4 — Hummocky disintegration moraine: mainly till; well-defined knobs and kettles, closed and linear disintegration ridges; large local relief
- 3 — Hummocky disintegration moraine: mainly till; knobs, closed and linear disintegration ridges; medium local relief
- 2 — Ground moraine: mainly till; patches of lacustrine and outwash sand, silt and clay; some knobs, closed and linear disintegration ridges; small local relief -- less than 10 feet
- 1 — Ground moraine: mainly till -- unsorted rocks, sand, silt and clay; patches of lacustrine and outwash sand, silt and clay; local relief less than 10 feet; includes valley fill deposits of till

CRETACEOUS

- A — Frenchman, Battle, Whitemud, Eastend, Bearpaw, Oldman and Foremost Formations: sandstone, shale, bentonitic clay and coal

Geological boundary -- definite .....

Geological boundary -- approximate .....

Ice-marginal channel .....

Postulated direction of meltwater flow .....

Glacial lineament .....

Geology by J.A. Westgate

Main highway ..... (45)

Local road, well travelled .....

Local road, not well travelled .....

Trail .....

Railway .....

Irrigation ditch .....

Township boundary .....

Section line .....

Cartography taken from Department of Lands and Forests, Alberta, Aerial Survey sheet No. 72E - 10

INDEX MAP

SURFICIAL GEOLOGY

WISDOM DISTRICT, ALBERTA

WEST OF FOURTH MERIDIAN

Scale: One Inch to One Mile 1/63,360

¾ ½ ¼ 0 1 2 3

LEGEND

QUATERNARY

RECENT

- Alluvium: sand, silt and clay; some gravel
- Lacustrine sediments: sand, silt and clay

PLEISTOCENE AND RECENT

- Colluvium and alluvial fan: sand, silt and clay; some alluvium
- Eroded slope: mainly bedrock; some glacial drift and colluvium
- Slump: mainly bedrock materials involved; some glacial drift and colluvium

PLEISTOCENE

GLACIO-FLUVIAL

- Outwash: gravel and sand; quartzites abundant
- Ice-marginal channel deposits: gravel and sand
- Ice-marginal channel deposits: silt and clay; commonly associated with recent lacustrine sediment. 14b - till present
- Collapsed ice-contact stratified drift: sand, silt and clay; some gravel
- Eroded plains: in part scoured by meltwater, gravel, sand, silt, and clay; bedrock exposures common; extensive badland

GLACIAL

- Controlled linear disintegration ridge: till, some gravel and sand
- Bedrock upland veneered with till: surface expression of drift commonly controlled by bedrock; gravel and sand in places
- *Hummocky end moraine: mainly till; aligned knobs; large to medium local relief*
- End moraine: aligned till ridges; some gravel and sand; medium local relief -- less than 20 feet
- End moraine: till veneered in places with gravel, sand, silt and clay; stony surface with many blowouts; saline soils; small local relief
- Hummocky disintegration moraine: mainly till; well-defined knobs and kettles, closed and linear disintegration ridges; large local relief
- Hummocky disintegration moraine: mainly till; knobs, closed and linear disintegration ridges; medium local relief
- Hummocky disintegration moraines: mainly till; stony surface in places, knobs often indistinct and blowouts common; saline soils; medium to small local relief
- Ground moraine: mainly till -- unsorted rocks, sand, silt and clay; some gravel and sand; small local relief -- less than 10 feet; includes valley fill deposits of till

CRETACEOUS AND QUATERNARY

- Bedrock-cored ridges (?) veneered with glacial gravel
- Bedrock with patches of glacial drift including Laurentian erratics

CRETACEOUS

- A — Bearpaw and Oldman Formations: dark shale; light-coloured shale and sandstone with coal seams

Geological boundary -- definite .....

Geological boundary -- approximate .....

Ice-marginal channel .....

Postulated direction of meltwater flow .....

Glacial lineaments .....

Site of numerous large erratic blocks of Cypress Hills Conglomerate .....

Fluting .....

Geology by J. A. Westgate

Main highway ..... (48)

Local road, well travelled .....

Local road, not well travelled .....

Trail .....

Railway .....

Irrigation ditch .....

Township boundary .....

Section line .....

Cartography taken from Department of Lands and Forests, Alberta, Aerial Survey

INDEX MAP

SURFICIAL GEOLOGY

GREEN LAKE DISTRICT, ALBERTA

WEST OF FOURTH MERIDIAN

Scale: One Inch to One Mile $\frac{1}{63,360}$

1 ¾ ½ ¼ 0 1 2 3

LEGEND

QUATERNARY

RECENT

- 22 — Alluvium: sand, silt and clay; some gravel
- 21 — Lacustrine sediments: sand, silt and clay
- 20 — Aeolian deposits: sand; parabolic dunes present

PLEISTOCENE AND RECENT

- R — Colluvium and alluvial fan: sand, silt and clay; same alluvium
- R — Eraded slope: mainly bedrock; same glacial drift and colluvium

PLEISTOCENE

GLACIO-LACUSTRINE

- 17 — Lacustrine sediments: sand, silt and clay; till in places; includes recent lacustrine sediment and alluvium
- 16 — Lake Pakawki sediments: sand, silt and clay; veneered with recent lacustrine sediment and alluvium
- 15 — Lake Pakawki sediments: lacustrine sand and till (undifferentiated)
- 14 — Delta: sand; pockets of greyish sand with glacial pebbles; fragmental bone material (mainly bison) and remains of Equisetum sp., both in situ and transported
- Delta: gravel and sand; large-scale festoon cross-bedding praminent

GLACIO-FLUVIAL

- 12 — Kame: mainly gravel and sand
- Spillway deposits veneered with recent lacustrine silt and clay
- 10 — Eraded plains: in part scaured by meltwater; till, gravel, sand, silt and clay; bedrock exposures common; extensive badland

GLACIAL

- Controlled linear disintegratian ridge: till; some gravel and sand
- 8 — Bedrock upland veneered with till; surface expression of drift commonly controlled by bedrock; gravel and sand in places
- 7 — Till ridge: some gravel and sand; ridge over 50 feet high
- 6 — Hummocky end moraine: mainly till; aligned knobs and closed disintegration ridges; large local relief
- 5 — End moraine: stony till; aligned and parallel ridges; large to medium local relief
- 4 — End moraine: till veneered in places with gravel, sand, silt and clay; stony surface with many blowouts; saline soils; small local relief
- 3 — Hummocky disintegratian moraine: mainly till; knobs, closed and linear disintegratian ridges; local relief less than 25 feet
- 2 — Ground moraine: till covered in places with gravel, sand, silt and clay; blowouts numerous; saline soils
- 1 — Ground moraine: mainly till -- unsorted rocks, sand, silt and clay; patches of lacustrine sand, silt and clay; local relief less than 10 feet; includes valley fill deposits of till

CRETACEOUS

- A — Bearpaw and Oldman Formations: dark shale; light-coloured shale and sandstone with coal seams

Geological boundary -- definite .....

Geological boundary -- approximate .....

Spillway or ice-marginal channel .....

Postulated direction of meltwater flow .....

Fluting .....

Glacial lineament .....

Geology by J.A. Westgate

Main highway .....

Local road, well travelled .....

Local road, not well travelled .....

Trail .....

Railway .....

Irrigation ditch .....

Township boundary .....

Section line .....

Cartography taken from Department of Lands and Forests, Alberta, Aerial Survey sheet No. 72E - 7

INDEX MAP

SURFICIAL GEOLOGY

MANYBERRIES DISTRICT, ALBERTA

WEST OF FOURTH MERIDIAN

Scale: One Inch to One Mile $\frac{1}{63,360}$

1 ⅜ ½ ¼ 0 1 2 3

LEGEND

QUATERNARY

RECENT

21 — Alluvium: sand, silt and clay; some gravel

20 — Aeolian deposits: sand

PLEISTOCENE AND RECENT

19 — Colluvium and alluvial fan: sand, silt and clay mixed, some gravel

18 — Eroded slope: mainly bedrock; some glacial drift and colluvium

PLEISTOCENE

GLACIO-LACUSTRINE

17 — Lake Wild Horse sediments veneered with recent lacustrine and alluvial silt and clay

16 — Lake Wild Horse sediments: mainly sand

15 — Lacustrine sediments: sand, silt, and clay; some gravel; till in places

GLACIO-FLUVIAL

14 — Undifferentiated outwash gravel and sand and till; bedrock exposed in places

Meltwater channel sediments: silt and clay; partly covered with alluvium and colluvium

12 — Esker: gravel and sand; in places local relief approaches 50 feet

11 — Kame: gravel and sand; local relief approximately 50 feet

10 — Ice-contact deposits: thin patches of gravel on till

9 — *Eroded plains: in part scoured by meltwater; till, gravel, sand, silt and clay; bedrock exposures common; extensive badland*

GLACIAL

8 — Hummocky end moraine: mainly till; aligned knobs and closed disintegration ridges; large local relief

7 — End moraine: aligned till ridges; medium to small local relief

6 — End moraine: till veneered in places with gravel, sand, silt and clay; stony surface with many blowouts; saline soils; small local relief

5 — Hummocky disintegration moraine: mainly till; knobs, closed and linear disintegration ridges; medium local relief

4 — Hummocky disintegration moraine: mainly till; stony surface in places, knobs often indistinct and blowouts common; saline soils; medium to small local relief

3 — Ground moraine: mainly till; some gravel, sand, silt and clay; saline soils; small local relief -- less than 10 feet

2 — Ground moraine: mainly till; in places some gravel, sand, silt and clay; knobs present; saline soils; small local relief

1 — Valley fill deposits: till -- unsorted rocks, sand, silt and clay

CRETACEOUS

A — Bearpaw and Oldman Formations: dark shale; light-coloured shale and sandstone with coal seams

Geological boundary -- definite .....

Geological boundary -- approximate .....

Meltwater channel .....

Subglacial tunnel .....

Postulated direction of meltwater flow .....

Drumlin or drumlinoid ridge: gravel and sand .....

Glacial lineament .....

Geology by J.A. Westgate

Main highway .....

Local road, well travelled .....

Local road, not well travelled .....

Trail .....

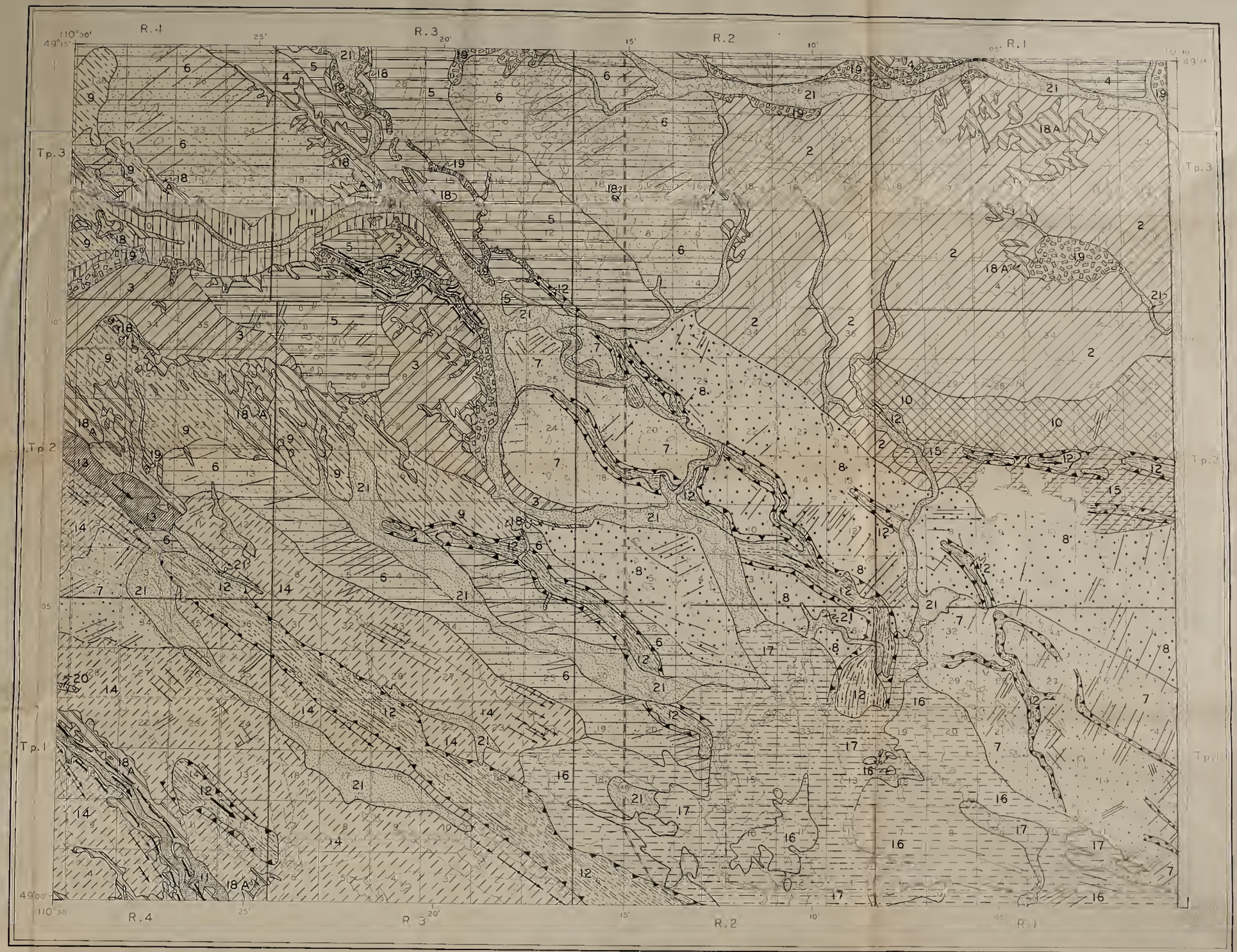
Railway .....

Irrigation ditch .....

Township boundary .....

Section line .....

Cartography taken from Department of Lands and Forests, Alberta, Aerial Survey sheet No. 72E - 1



INDEX MAP

SURFICIAL GEOLOGY

WILD HORSE DISTRICT, ALBERTA

WEST OF FOURTH MERIDIAN

Scale: One Inch to One Mile $\frac{1}{63,360}$

1 ⅜ ½ ⅛ 0 1 2 3

LEGEND

QUATERNARY

RECENT

17 — Alluvium: sand, silt and clay; some gravel; includes terraces

16 — Lacustrine sediments: sand, silt and clay; some alluvium

15 — Aeolian deposits: sand

PLEISTOCENE AND RECENT

14 — Colluvium and alluvial fan: sand, silt and clay mixed; some gravel

13 — Eroded slope: mainly bedrock; some glacial drift and colluvium

PLEISTOCENE

GLACIO-LACUSTRINE

12 — Lake Pokowki sediments: sand, silt and clay; veneered with recent lacustrine sediment and alluvium

11 — Lake Pokowki sediments: shoreline deposits of sand with some gravel

10 — Lake Pokowki sediments: thin shoreline deposits of gravel and sand overlying till

GLACIO-FLUVIAL

9 — Undifferentiated outwash gravel and sand and till; bedrock exposed in places

8 — Meltwater channel sediments: sand, silt and clay; some gravel; partly covered with alluvium, colluvium and recent lacustrine sediment

7 — Eroded plains: in part scoured by meltwater; till, gravel, sand, silt and clay; bedrock exposures common; extensive badland

GLACIAL

6 — End moraine: oligned till ridges; some gravel and sand; large to medium local relief

5 — End moraine: till veneered in places with gravel, sand, silt and clay; stony surface with many blowouts; saline soils; small local relief

4 — Hummocky end moraine: mainly till; knobs; large to medium local relief

3 — Ground moraine: mainly till; some gravel, sand, silt and clay; saline soils; small local relief -- less than 10 feet

2 — Ground moraine: mainly till; grooved; bedrock at surface in few places; generally less than 10 feet thick; small local relief

1 — Valley fill deposits: till -- unsorted rocks, sand, silt and clay

CRETACEOUS

A — Bearpaw, Oldman, Foremost and Pakowki Formations: sandstone, shale, bentonitic clay and coal

Geological boundary -- definite .....

Geological boundary -- approximate .....

Meltwater channel (includes ice-marginal and spillway channels) .....

Postulated direction of meltwater flow .....

Drumlin or drumlinoid ridge: gravel and sand .....

Fluting .....

Glacial lineament .....

Geology by J. A. Westgate

Main highway .....

Local road, well travelled .....

Local road, not well travelled .....

Trail .....

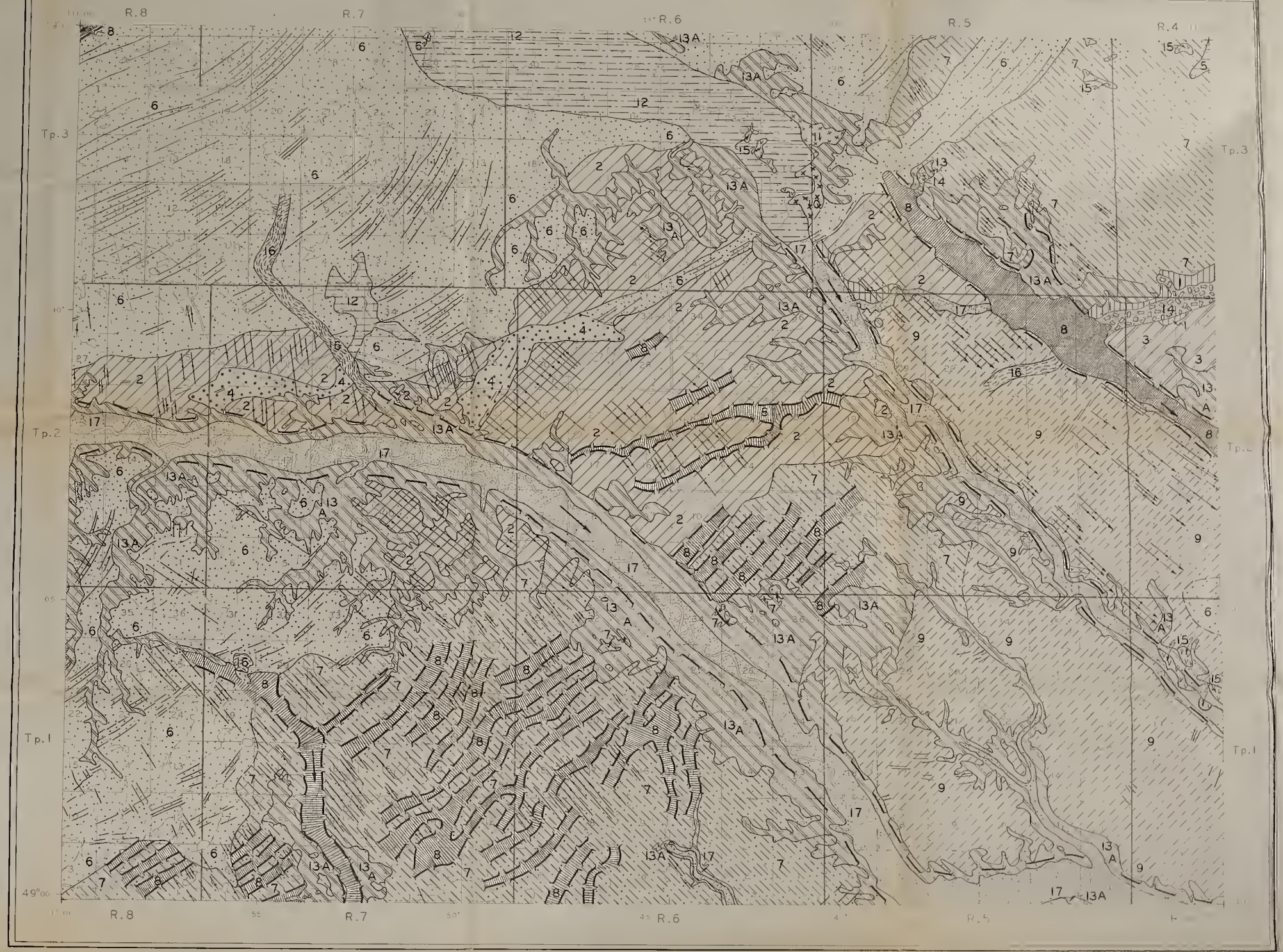
Railway .....

Irrigation ditch .....

Township boundary .....

Section line .....

Cartography taken from Department of Lands and Forests, Alberta, Aerial Survey sheet No. 72E - 2



INDEX MAP

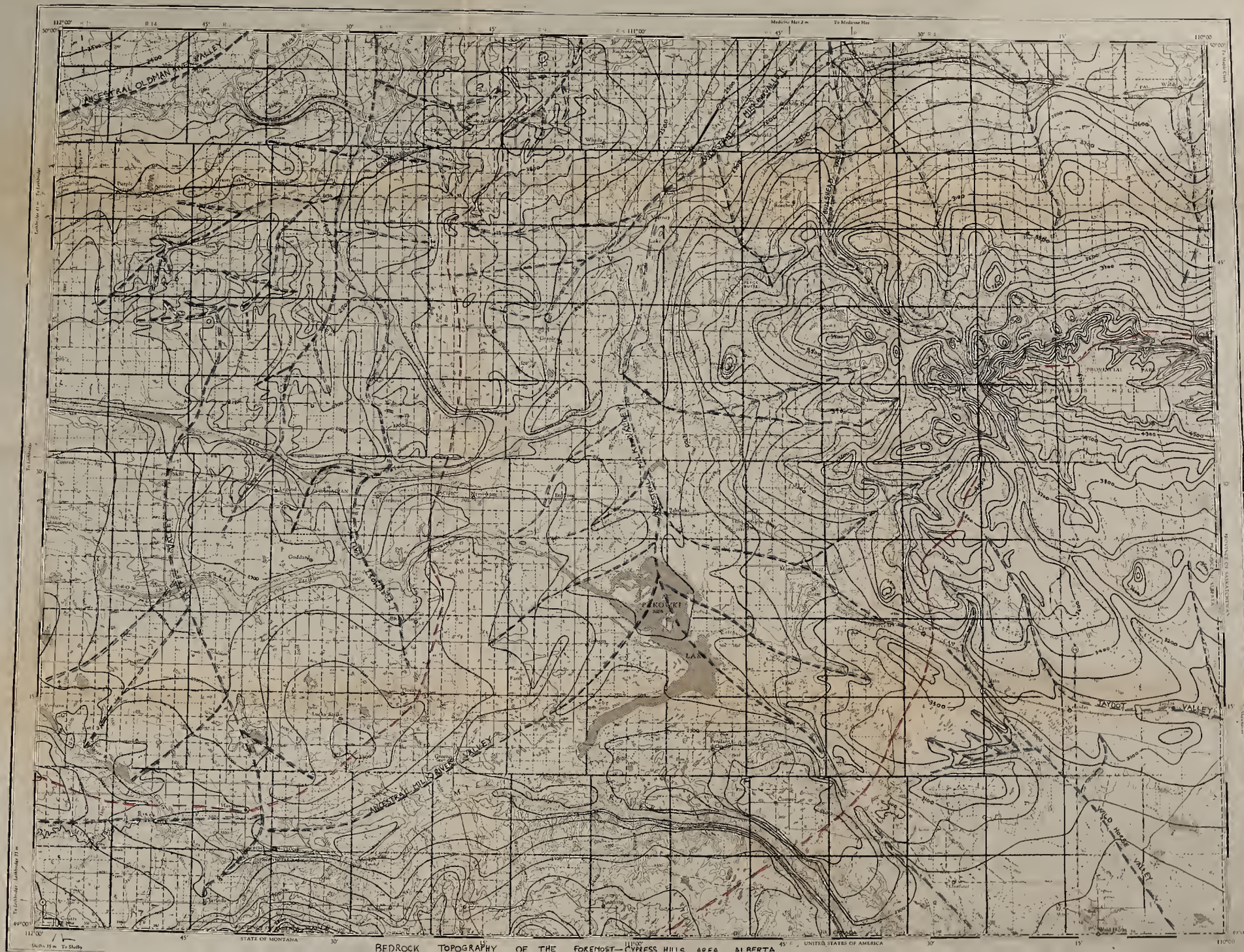
SURFICIAL GEOLOGY

COMREY DISTRICT, ALBERTA

WEST OF FOURTH MERIDIAN

Scale: One Inch to One Mile $\frac{1}{63,360}$

1 ¾ ½ ¼ 0 1 2 3



EXPLANATION

Contour, bedrock surface 2500

Thalweg of preglacial valley .....

Preglacial drainage divide .....

See below for comments on reliability of contours

Scale in Miles

4 3 2 1 0 4 8

Contour interval = 100 feet

Elevations in feet above mean sea level

Bedrock topography by J. A. Westgate, 1964

Control points (mainly from seismic shot point data) spaced one mile apart or less over greater part of western half of sheet

Contours in eastern half drawn up largely from field evidence

Map drawn to scale 1 inch to 2 miles and reduced to 1 inch to approximately 4 miles

BEDROCK TOPOGRAPHY OF THE FOREMOST—CYPRESS HILLS AREA, ALBERTA

NATIONAL TOPOGRAPHIC SYSTEM 1:250,000 CANADA FIRST EDITION SHEET 72E

LEGEND

- 4 — Glacial drift more than 100 feet thick
- 3 — Glacial drift 50–100 feet thick
- 2 — Glacial drift 0–50 feet thick
- 1 — Cypress Hills Plateau: unglaciated; some loess, generally less than 5 feet thick

Boundary fairly well defined .....

Boundary approximate .....

THICKNESS OF DRIFT IN THE FOREMOST–CYPRESS HILLS AREA, ALBERTA

FOREMOST

ALBERTA

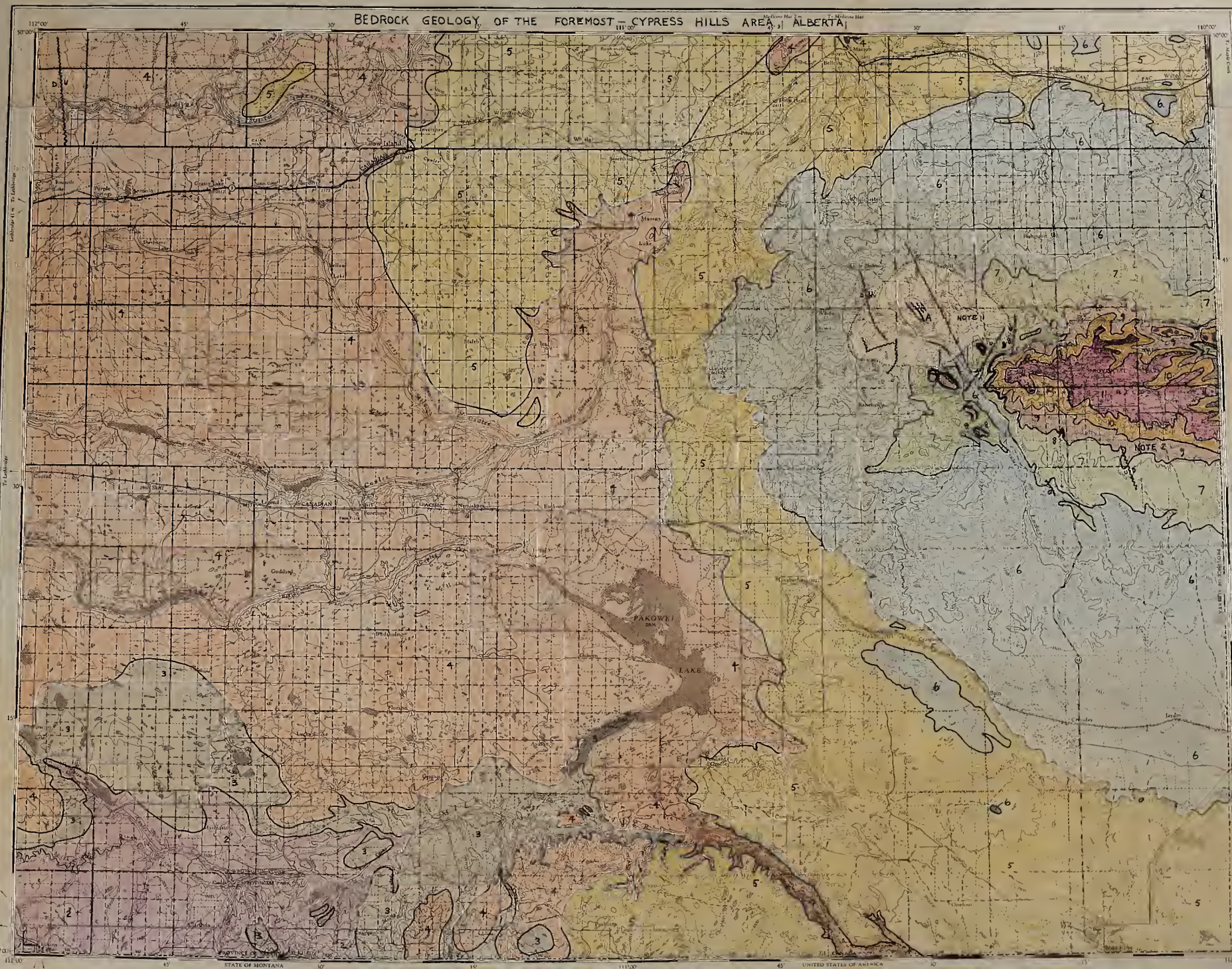
WEST OF FOURTH MERIDIAN

Scale 1:250,000

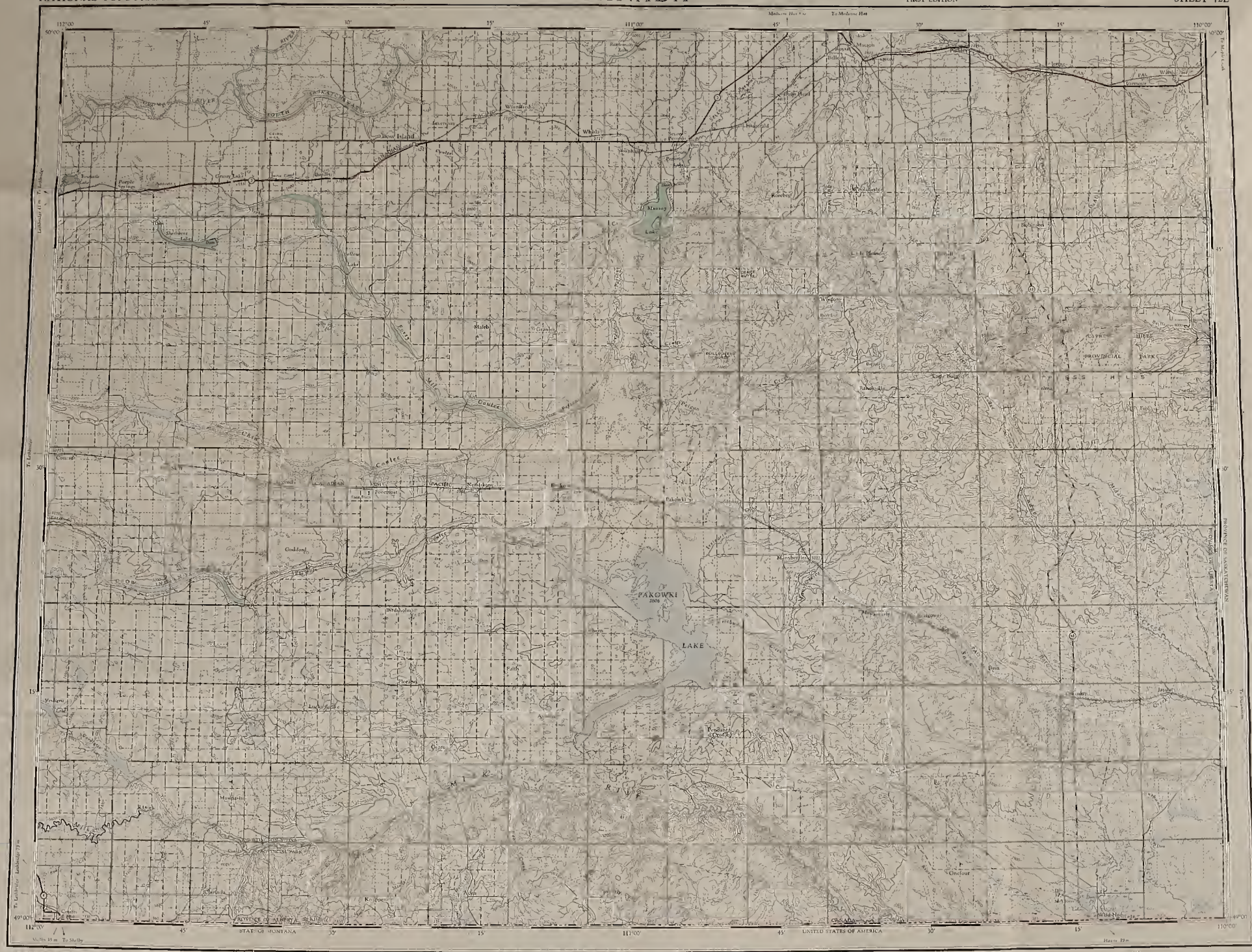
1 Inch to 4 Miles Approximately

REFERENCE

BEDROCK GEOLOGY OF THE FOREMOST – CYPRESS HILLS AREA, ALBERTA


NOTE 1
NOTE 2
PAKOWKI LAKE
Medicine Hat
Redcliff
Bow Island
Foremost
Dunmore
Suffield
Manyberries
Elkwater
Irvine
Rosemary
Brooks
Tilley
Gem
Scandia
Bantry
Hilda
Schuler
Veteran
Jenner
Patricia
Empress
Walsh
Dunkirk
Orion
Cypress Hills Provincial Park
Elkwater Lake
Middle Lake
Gros Ventre Creek
Ross Creek
Seven Persons Creek
Bullshead Creek
Many Berries Creek
Milk River
Lodge Creek
Battle Creek
Ross Coulee
Irvine Creek
Bullhead Creek
Sage Creek
Verdigris Coulee
Bullshead Coulee
Seven Persons Coulee
Many Berries Coulee
Lodge Coulee
Battle Coulee
Irvine Coulee
Ross Coulee
Sage Coulee

NATIONAL TOPOGRAPHIC SYSTEM 1:250,000 CANADA FIRST EDITION SHEET 72E



FOREMOST

ALBERTA

WEST OF FOURTH MERIDIAN

Scale 1:250,000

1 Inch to 4 Miles Approximately

REFERENCE

REFERENCE

B29827